THE
RICE INSTITUTE
PAMPHLET

ol. XI January, 1924 No. 1

Published by
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university of liberal and technical learning
unded by William Marsh Rice in the City
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UNIVERSITY EXTENSION LECTURES

I

THE ELECTRICAL VIEW OF MATTER

ACCORDING to Dalton's atomic theory, put forward in 1803, any particular chemical element, for example, iron, is composed of minute particles or atoms, all exactly equal in weight and all other properties. The atoms of different elements have different weights and the relative atomic weights, which play so important a part in chemistry, express the weights of the different atoms on a scale such that the atomic weight of oxygen is 16 and that of hydrogen slightly more than unity. About 90 different elements are known, and it is remarkable that many of them have atomic weights which are very nearly whole numbers, for example carbon 12.00, nitrogen 14.01, sodium 23.00, sulphur 32.06. There are however several elements the atomic weights of which are not whole numbers, such as chlorine 35.46, magnesium 24.32, and hydrogen 1.008.

The fact that many atomic weights are whole numbers naturally suggests that the atoms may be built up out of smaller bodies of atomic weight unity. This idea was suggested by Prout in 1813 but was given up when it was definitely established that some elements have atomic weights which are not exactly integers.

The chemical operations by which atomic weights are determined always involve enormous numbers of atoms, so that what is really found is the average atomic weight for an immense number of atoms; and the assumption that all the atoms of any one element are exactly equal is not really tested by chemical experiments. Sir William Crookes, in 1886, suggested that all the atoms of an element may not be exactly equal and that atomic weights may be merely averages, but these views were not taken very seriously at that time. Recent researches have shown that Prout's hypothesis of 1813 and this suggestion of Crookes are both correct.

Up to about thirty or forty years ago atoms were usually thought of as hard indivisible particles, exciting a field of force in the space around them. We now know that all matter contains electrons which are minute particles of negative electricity all exactly equal. These electrons are emitted by hot bodies and their properties have been carefully studied by Sir J. J. Thomson and many other physicists. They have been shown to be all equal by precise experiments and the weight of one electron is only about one two thousandth of that of one hydrogen atom. Since all kinds of matter contain these electrons it is natural to enquire how many of them go with each atom. We might expect some atoms to have one electron, some two, some three and so on, and we might expect the number per atom to increase with the atomic weight. As a matter of fact, an examination of all the known chemical elements has verified both of these expectations concerning the variation in the number of electrons per atom as we pass from element to element. It is found that hydrogen atoms each contain one electron, helium atoms two, lithium atoms three and so on up to uranium atoms which each contain 92 electrons. If we make a list of the elements in the order of their atomic weights then each element in the list has one more electron per atom than the element preceding it. Thus the first eleven elements in such a list are:

Element	*Atomic Weight*	*Electrons per atom*
Hydrogen	1.008	1
Helium	4	2
Lithium	6.94	3
Beryllium	9.1	4
Boron	10.9	5
Carbon	12.00	6
Nitrogen	14.008	7
Oxygen	16	8
Fluorine	19.00	9
Neon	20.20	10
Sodium	23.00	11

Electrically neutral atoms must contain as much positive electricity as negative, so that, for example, a neutral carbon atom containing six electrons must also contain as much positive electricity as there is negative in six electrons. It has been shown by Sir Ernest Rutherford, the successor of Sir J. J. Thomson in the chair of experimental physics at Cambridge University, that the positive electricity in atoms is in the form of an extremely minute particle or nucleus which has nearly all the weight of the atom. The electrons are believed to move in orbits round this positive nucleus in much the same way that the planets move round the sun. Thus an atom is now thought of as like a minute solar system. The positive nucleus attracts the electrons, but the electrons repel each other; whereas in the solar system the sun and planets all attract each other. The chemical properties of the elements are believed to depend on the number of electrons per atom and especially on the stability of the arrangement of the electrons. Thus an atom which easily loses an electron, so acquiring a positive charge, is an electropositive atom; while an atom which easily takes on an additional electron is an electronegative atom. An atom which easily loses an electron readily combines with an atom which easily gains an electron, and in the compound of the two atoms one has lost and the other gained an electron. The two atoms are then held together by the attraction between the positive charge on one and the negative charge on the other.

The gases helium, neon, argon, krypton and xenon discovered by Rayleigh and Ramsay are remarkable in that they have no chemical properties. They form no compounds with other elements. The atoms of these gases do not easily lose or gain electrons. The electrons in them form very stable systems. Helium has 2 electrons per atom, neon 10, argon 18, krypton 36 and xenon 54. Thus it appears that these numbers of electrons form stable systems in an atom. An atom with one electron less than one of these stable systems, for example, a chlorine atom which has 17 electrons, one less than argon, readily takes on one extra electron, so forming a stable system of 18, like argon but with a negative charge. In the same way an atom with one more electron than one of the inactive gases, for example, a potassium atom which has 19 electrons, readily loses an electron forming a stable system like argon but with a positive charge. Thus, potassium is an electropositive element, and chlorine an electronegative element; and they readily combine into a stable compound, potassium chloride, in which there are 36 electrons per molecule, 18 in the potassium atom and 18 in the chlorine atom.

Atoms with two electrons less than one of the inactive gases readily gain two extra electrons, and atoms with two more readily lose two. Thus, calcium which has 20 electrons, and sulphur, which has 16, readily combine, forming a molecule with 36 electrons, 18 in the calcium atom and 18 in the sulphur atom.

In this way, originally due to Sir J. J. Thomson, many of the chemical properties of the elements have been explained. The chemical properties of an atom depend on the number of electrons it contains in its electrically neutral state when the negative charge on its electrons is equal to the positive charge on its nucleus. The atomic weight of the atom is determined by the weight of its nucleus.

The weight of the nucleus, that is, the atomic weight, does not on this view determine the chemical properties. It is the charge of positive electricity on the nucleus which is important, because this determines the number of electrons in the neutral atom.

A given quantity of a chemical element consists of a large number of atoms all having the same chemical properties, and, therefore, all having the same nuclear charges and the same number of electrons when in the neutral state. It has usually been assumed that all the atoms of a chemical element have equal weights, but we see now that this may not be true, because the chemical properties do not depend on the weight, so that a mixture of atoms of different weights would behave as an element if all the atoms had equal nuclear charges.

The fact that many atomic weights are very nearly whole numbers suggests that the nuclei of these atoms may be built up out of units of atomic weight one, presumably hydrogen atoms. We should expect all atoms to be similarly built up, but some atomic weights are not whole numbers, for example, chlorine 35.45. All the atoms of chlorine have the same chemical properties, but not necessarily equal weights. The atomic weight 35.45 may, therefore, be an average weight of atoms all of which have atomic weights exactly whole numbers. Thus, a mixture of atoms with weights 35 and 36 could have an average weight 35.45. Recent researches by Sir J. J. Thomson and F. W. Aston have shown clearly that this is the true explanation of fractional atomic weights. Chlorine is found to be a mixture of atoms of weights 35, 37 and 39; neon, a mixture of 20 and 22; magnesium, 24, 25 and 26, and so on.

The atomic weight of hydrogen, however, is 1.008, so that when, say, 16 hydrogen nuclei are combined to form an oxygen nucleus we should expect its weight to be 16.128 whereas the atomic weight of oxygen is 16 exactly. It appears that when hydrogen nuclei combine, forming heavier nuclei, there is a loss of weight of 0.008 for each hydrogen nucleus. This is believed to be the weight of the energy which is lost during the combination. One gram of hydrogen according to this must give out an enormous amount of energy on combination into heavier elements. The amount is calculated to be more than 20,000 horse power for one hour.

Thus, if ever it becomes possible to bring about the combination of hydrogen atoms into heavier elements, an inexhaustible supply of energy will be made available. The danger is that such a process once started might proceed with explosive violence and involve all the hydrogen on the earth. If this should happen, the heat involved would be sufficient to volatilize the whole earth and convert it into a new star.

Harold A. Wilson

II

INSULIN IN DISCOVERY AND USE

THE discovery and use of insulin for the treatment of diabetes is a recent outstanding achievement of science. In recognition of the great service thus rendered to mankind, the discoverer, Dr. F. G. Banting, received the Nobel Prize in Medicine for 1922. Such recognition alone signifies that the scientific research in this field carried on during the last few years by Dr. Banting and his associates at the University of Toronto is considered by competent authorities to be of fundamental importance to the progress of medical science.

Before taking up the main part of my thesis on the discovery and use of insulin, it might be well to discuss briefly the fundamental causes and physiological aspects of diabetes, in order to understand more clearly the source of the discovery of insulin and the reasons for its use; for the discovery of insulin was by no means accidental, but decidedly the result of a direct search by a man who knew just what he was looking for, and approximately where to find it.

Diabetes is classified as one of the diseases of metabolism, that is, a disease resulting from an improper diet or the failure of the digestive system to utilize with the greatest efficiency the common foodstuffs of a normal diet. One authority defines diabetes very simply as "a disease in which the metabolism of carbohydrates, together with that of the fats, is disturbed." This simply means that the digestive mechanism of a diabetic is for some reason unable to utilize fully the chemical compounds that constitute by far the largest part of our foodstuffs. Other more or less familiar types of diseases of metabolism are scurvy, beri-beri, and pellagra in adults, and rickets in children. These diseases differ from diabetes in that certain vitally important substances known as vitamines are lacking in the diet, whereas the cause of diabetes is not due to a deficiency of any certain ingredients in the diet, but rather to a deficiency of some necessary substance contained in the body.

Since, according to the definition, diabetes is a disease in which the metabolism of carbohydrates and fats is upset, let us consider first the normal path followed by the carbohydrates and fats in the animal body.

The starches contained in our foodstuffs, on passing from the mouth to the stomach and then to the intestine, are decomposed into smaller and less complicated substances known as the simple sugars. These simple sugars, three in number, are then absorbed from the intestine by the venous blood stream, and carried directly to the liver, where, by some unknown process, these three sugars are converted into one sugar known as glucose, or sometimes called dextrose. Therefore, at this point, the starches of the diet are present as the one substance. A certain amount of the glucose then passes from the liver into the main blood-stream to maintain a constant supply of about 0.1 per cent., the rest remains stored in the liver in an easily available form for future use. The blood now circulates through the muscular tissue of the body, where the glucose is burned to carbon dioxide and water, energy being liberated in this process. This is the path, briefly, of the fate of carbohydrates in the metabolic processes of the individual in normal health.

In the diabetic, however, the process of carbohydrate metabolism follows the normal path as outlined, up to the point only where the glucose leaves the liver in passing into the main blood-stream. The glucose now contained in the blood-stream is not completely burned to carbon dioxide and water as takes place normally; on the contrary, some glucose remains in the blood-stream. With the consumption of more carbohydrates in the diet, more and more glucose is eventually poured into the blood, until at last a certain percentage of glucose is reached which may be two to three times the concentration normally found. The actual concentration of glucose reached in the blood of different diabetic patients varies within certain limits, depending on the individual. Finally, the concentration of the glucose in the blood rises to such an extent that no more can be absorbed. At this point, the kidneys begin to eliminate the glucose by absorbing it from the blood, and excreting it in the urine. The presence of glucose in the urine, therefore, is one of the danger signals of the onset of diabetes. However, the presence of glucose in the urine does not necessarily indicate diabetes, for after a meal consisting of a heavy carbohydate diet, and after certain violent emotional conditions, glucose is often found in the urine. This condition does not last very long, and the glucose soon disappears in the normal person; in the diabetic, however, glucose appears persistently in the urine.

It has been known for a long time that the combustion of glucose in the blood is controlled by four glands in the body, namely, the adrenal, thyroid, pituitary, and pancreatic glands. Of these, the pancreas has been shown to have the greatest effect. The pancreas is a small gland located just under the stomach. It is composed of two parts, one of which secretes the pancreatic juice into the intestine, and the other part which is composed mainly of certain cells known as the Islands of Langerhans. It has been known for a long time that the function of these islands is to secrete into the blood a substance in the presence of which combustion of glucose into carbon dioxide and water takes place. Therefore, it is the failure of these islands to function properly which causes the glucose to remain in the blood unburned, and thus produces diabetes. The fundamental cause of diabetes is, therefore, the failure of the pancreas to function properly, the metabolic cause being only of secondary importance.

When glucose cannot be properly burned, the metabolism of fats is also upset. The normal digestion of fats follows a somewhat similar path to that taken by the carbohydrates. In passing from the mouth into the stomach, and thence into the intestine, the fats are decomposed into two products, namely, the fatty acids and glycerine. These products are then absorbed from the intestine by the lymphatic system, and soon find their way into the main blood-stream. Here, the fatty acids and glycerine are burned to carbon dioxide and water in a way similar to the sugar combustion, also supplying energy to the muscular tissue.

In a diabetic patient, however, these fatty acids are not completely burned to carbon dioxide and water, but stop short of the normal combustion, being only partly burned. These partly burned products are known as the acetone bodies. Prior to 1914 this failure of incomplete fat metabolism was not generally recognized as one of the symptoms of diabetes, and furthermore, it was not until several years after this time that the reason for incomplete fat metabolism accompanying incomplete carbohydrate metabolism was known. The reason for this complication is this: in order for the fatty acids to be completely burned to carbon dioxide and water, the glucose in the blood must also be completely burned. Or, as one authority cleverly puts it, "Fats burn in the flames produced by the burning of the sugar." This relationship between these two processes is an experimental fact, but as yet we have no satisfactory explanation of the fact. These partially burned fatty acids, the acetone bodies, remain in the blood-stream, and are ultimately removed by the kidneys and excreted in the urine. Therefore, the onset of diabetes is recognized primarily by the continued presence of glucose and the acetone bodies in the urine. Of course other physical symptoms appear, such as loss of weight, thirst, and general weakness.

Here let me summarize the foregoing facts. From a study of the chemical and physiological causes of diabetes, we can say briefly:

First, the primary cause of the onset of diabetes is due to the failure of the Islands of Langerhans, located in the pancreas, to secrete into the blood a certain substance which is necessary for the complete combustion of the normal amount of glucose in the blood.

Second, due to this fact, the amount of glucose in the blood rises considerably above the normal 0.1 per cent., until a certain concentration known as the "leak-point" is reached. The excess glucose now overflows through the kidneys, and is eliminated in the urine.

Third, attending the failure of complete sugar metabolism and complicating this state, is the incomplete metabolism of the fats, due to the fact that the second process depends wholly on the first. This results in the formation of the acetone bodies in the blood, and their subsequent elimination in the urine.

Since the present method of treatment of diabetes with insulin depends to a great extent on the older methods, it might be well to consider these briefly. Prior to 1914, diabetic patients were overfed, all cases being treated with a low carbohydrate and a high protein-fat diet. This was before the medical profession recognized the fact that fats played a minor part in the disease. The giving of diets of large calorific value was encouraged, and fats and fatty foods were given to an enormous extent. To guard against coma, one of the complications of diabetes, gradual restrictions of the diet were advised, and sodium bicarbonate (ordinary baking soda) was employed in large doses. The value of fasting and of giving limited calorific diets was not grasped by the medical profession in general until late in the year 1914, when, in consequence of Allen's investigations, the principle of fasting and under-nutrition was introduced. Even then, it was not until late in the year 1915 that this practice became the general rule. This change in the method of treatment profoundly affected the metabolism of diabetics. Also, at this time, fats were recognized to be a source of complication, as I have already pointed out; so that they were eliminated from the diet.

The dietetic treatment used in general to-day is essentially that advised by Allen, namely periods of fasting, interspersed with periods of under-nutrition, closely following the course of the metabolic processes with urine analyses for sugar and the acetone bodies. No commonly known drug has any influence on the metabolism of sugar. Purgatives and general tonics for the health are sometimes used.

Diabetes is not in itself the actual cause of death, rather it is the complications arising from severe cases of diabetes that result fatally. Of the several known types of complications that may follow, only two are prevalent enough to discuss. The most common complication is that of coma. Before the treatment of diabetes was fully understood, this was the frequent termination of the disease. Prior to 1914 Allen reports that eight-six per cent. of diabetic patients died in coma. With a better understanding of the method of treatment, that is dietetic treatment alone, this rate dropped steadily, until, in 1919, only fifty-two per cent. died of this complication. Coma is now the result only in untreated, very severe, and long-standing cases, wherein the choice lies between death from under-nutrition or coma from overfeeding. Of course, I have not as yet touched upon the prevention of coma by the use of insulin, but this will be presented later. Pneumonia is responsible for the death of a small percentage of diabetic patients. During the period 1908-1917, the mortality rate was about eight per cent. Other complications are much smaller in extent.

We have now considered the chemical and physiological causes of diabetes, the fatal complications resulting from it, and the less recent methods of dietetic treatment. Up to the year 1922, the only method of treatment used was that from a dietetic standpoint. In this year, with the discovery of insulin by Banting and his associates, the old method of treatment changed. Before taking up this phase of the value of insulin, let us first consider the early investigations which led to its discovery. During the period, 1885-1900, several German and French investigators showed conclusively that the removal of the pancreas from dogs was accompanied by the appearance of symptoms of diabetes. The content of blood-sugar rose above the normal level, and sugar was also excreted in the urine. This was the first time that the all-important relation between the active functioning of the pancreas and the combustion of sugar was shown. In 1909, Zuelzer, a German investigator, attempted to extract the active principle from the pancreas. His methods of extraction were poor, but he did get an extract which produced some slight effects on the combustion of the blood-sugar. He administered this extract to several of his patients with but partial success, and soon abandoned the practice, since his extract was quite toxic, and the good results produced were offset by the toxic effects. In the light of our present knowledge of the isolation of insulin, Zuelzer's method was sound, but his investigations were not comprehensive nor conclusive enough for him to receive the credit for the discovery of insulin. E. L. Scott, an American, working at the University of Chicago in 1912, also attempted to isolate the active principle from the pancreas. His work was likewise unproductive of any startling results, yet his method of extraction was quite similar to that later employed by Banting with great success. In 1913, two other investigators made extracts of the pancreas and injected their preparation into diabetic dogs with moderate success. They, also, failed to carry their investigations sufficiently far before discontinuing their work.

Such was the state of affairs in November, 1920, when Dr. Banting happened upon some passages in medical literature which suggested to his open mind a rational method for the isolation of this elusive substance. The facts upon which he based his subsequent investigations were these: in 1890, Langerhans found from a minute observation of the pancreas, that there were present in the main part of the gland certain very small cells which had hitherto escaped notice. These cells seemed to him to have a different cellular structure, and to have a different function from the other cells of the gland. It was shown that these islands did have a different function when it was observed that in the case of patients dying from diabetes these Islands of Langerhans were found to be destroyed. An experiment had also confirmed this fact, for when the duct leading out of the gland was tied, and the gland allowed to degenerate as all unused organs do, the Islands of Langerhans remained unaffected, and the metabolism of glucose was not interfered with in any way.

Dr. Banting put a great deal of thought during the next six months on developing a suitable method for the isolation of this active principle from the pancreas. He studied very carefully the methods used by other men and the reasons for their failure. Finally he hit upon the following plan which he thought could be carried out to a successful result. Other investigators had simply extracted the active principle from the fresh organ. Their extracts had shown signs of containing some of the desired active principle, in that they produced some of the desired effects. But their extracts were very weak, and they were also toxic. Therefore, some other substance had simultaneously been extracted which destroyed the desired active principle. If this view be correct, Banting inquired, why not shut off the outlet of the pancreas in dogs, allow the gland to degenerate without injuring the Islands of Langerhans, as had been shown to be possible, and then extract the active principle from the islands after the rest of the pancreas has disappeared.

With his plan of attack thus worked out, he dropped his professional practice in London, Ontario, and went to the University at Toronto, where he talked to Professor J. J. R. McLeod, a noted physiologist and an authority in the field of metabolism. Professor McLeod agreed that Banting's plan was feasible, and gave him the necessary equipment and help to carry on his investigation, and assigned Mr. C. H. Best to work with him.

Several young dogs were obtained, and the pancreatic duct leading to the intestine was tied off. Ten weeks later, after the gland had completely degenerated, the dog was killed and the pancreas removed. This pancreas was then extracted with suitable liquids, and the liquid extract injected into dogs who were suffering from diabetes. The results confirmed Banting's hypothesis. The blood-sugar content immediately decreased. Other dogs were taken and their pancreatic glands removed. These dogs developed very severe cases of diabetes, but were kept alive indefinitely by regular daily injections of insulin. Without the constant injection of insulin the dogs quickly died.

Shortly after this Banting and Best prepared insulin from the pancreas of beeves. This extract was more powerful than the first one obtained, and was also less toxic, in that it produced less local irritation after the injection. This extract was not only tried on diabetic dogs, but was also tried on diabetic patients in the hospitals of Toronto. A decrease in the blood-sugar concentration, and the disappearance of sugar in the urine resulted in all cases. There was also some slight local irritation encountered in some of the cases, due to the presence of foreign proteins in the extract as impurities. The noteworthy result from this last method of preparation was this: it gave evidence that insulin could be prepared from a readily available source, namely from the beef pancreas obtained from our large stockyards.

With this fact as an incentive, an enormous amount of work was carried out by the investigators at Toronto to determine the best and cheapest method for preparing extracts of insulin. A half-dozen or more different methods of extraction were tried, using both hot and cold water, alcohol, benzoic acid, and other substances. Varying degrees of success were attained. Numerous variations in the physical conditions attending the operations were tried, all with the sole idea of producing insulin in the largest quantities possible and in the highest state of purity.

The method now used and controlled by the Toronto group, is a combination of the best points developed in the many variations attempted. Fresh pancreatic glands are obtained from beeves, and as much as possible of the attendant fat and connective tissue are removed. They are then ground in an ordinary meat chopper, placed in large vats and covered with ordinary grain alcohol. After a short time, the alcohol has extracted the insulin from the glands. The alcohol is next separated from the residue by filtration, and the alcoholic extract concentrated to a smaller volume. Ether is then added, causing the insulin to precipitate out as a fine white powder which is separated from the liquor, and dried. This white powder is then redissolved in sterile water, containing a slight amount of acid, and is used in this condition for medical work. This, of course, is a very brief outline of the essential points of the process which is much more detailed than I have indicated.

In any type of commercial manufacture, it is always the aim of the producer to get the maximum amount of the desired product from the smallest amount of initial material. So it is with the preparation of insulin. In April, 1922, the Toronto laboratories were able to get but fifteen units of insulin from two pounds of beef pancreas. Due to the various improvements in their methods, they have increased the yield to four hundred units from two pounds of pancreas. These latter figures are for July, 1923. Since that time, they have no doubt increased these figures considerably. The Toronto laboratories have done a great deal of work on the extraction of insulin from pork pancreas. This type of pancreas furnishes a relatively larger amount of insulin per pound than the beef pancreas, but the greater difficulty in handling it, with its increased cost, offsets the advantage of the higher yield.

As is always the case with the discovery of any new substance of value, everybody starts looking for the same thing in various other sources. A Dallas physician reports the isolation of an insulin-like substance from yeast. Dr. Collip, one of Banting's co-workers, has shown that insulin can be extracted from certain types of clams. Other animal sources, such as certain types of fish, the liver, spleen, thymus and thyroid glands of different animals and man, also give evidence of the presence of an insulin-like substance. The plant kingdom likewise, for instance, lettuce and onion and beet tops, have furnished insulin-like substances of slight importance. These, however, have yet to be thoroughly investigated.

With the preparation and use of insulin past the first experimental stage, it was the desire of the Toronto investigators to place this drug on the market as soon as possible. It was obviously impossible to manufacture in the little laboratories at the University of Toronto, insulin in large enough quantities to alleviate the suffering of all the diabetics in Canada and this country. The Toronto group also realized that to throw into the market the plans for the preparation of so valuable and important a drug as insulin would cause a great deal of unnecessary confusion and danger. They, therefore, appointed the Connaught Laboratories at Toronto to be the sole manufacturers of insulin for the Dominion. Banting and his co-workers formed themselves into a body, now known as the Insulin Committee, with direct control over its manufacture. The Connaught Laboratories have recently received from the Canadian Government an appropriation of twenty-five thousand dollars to be used in buying the necessary equipment for the preparation of insulin.

To supply the American demand, the Insulin Committee after careful consideration decided to invite representatives of the Eli Lilly Company, of Indianapolis, to come to Toronto to discuss the question of manufacture in this country. As a result of this conference an agreement was entered into whereby the Eli Lilly Company was granted an exclusive license in the United States for the manufacture of insulin, for an experimental period set provisionally at one year, under the following conditions:

First, that the firm use all of its available facilities and personnel for the manufacture of the product, and pay all expenses entailed in its manufacture on a large scale in their plant.

Second, that the firm submit samples of their product to the University of Toronto for approval before distribution to physicians for use on patients.

Third, that the approved product be distributed either free or at cost price only, to such physicians as may be chosen in consultation with the University of Toronto.

In consideration of the acceptance of these conditions by the Eli Lilly Company, on May 31st, 1922, all known details of the method of manufacture were given to the firm, and large scale production was immediately started.

The Insulin Committee showed commendable foresight by keeping direct control of the manufacture and standardization of this drug, for, as always follows in the wake of the introduction of a new drug, other manufacturing companies have been exploiting utterly worthless preparations which they "guaranteed to be just as good". The Eli Lilly Company product appears on the market as "Iletin". It comes in five cubic-centimeter vials of two different strengths. The weaker solution contains ten units per cubic-centimeter, and the stronger solution contains twenty units per cubic-centimeter. This latter solution of one hundred units sells at two dollars per vial, which is two cents a unit, a remarkably cheap price for so valuable a drug.

Since entering into the agreement with the Eli Lilly Company, the Insulin Committee has made similar arrangements with several European countries. England, Germany, and the Scandinavian countries are now producing insulin for their own respective use under the direct control of the Toronto group. In Denmark, in particular, large quantities of insulin are being produced, the highly developed swine industry of that country providing a fertile source for the production of the drug from the pork pancreas. Extraction of insulin from the pork pancreas had been attempted in Canada, but the process was discarded as impracticable; investigators in Denmark, however, have overcome the obstacles to this method, and are now making a very pure product.

I have already stated that the Insulin Committee also controls the standardization of insulin solutions. This is a very important factor in its use. Due to the fact that insulin is a chemical compound of unknown composition and structure, it cannot be analysed by any of the common chemical methods. Resort must therefore be had to a biological method of standardization. The insulin unit is defined as "one-third the amount which lowers the percentage of blood-sugar in a normal rabbit weighing 2 kg. (i.e. approximately four pounds), starved for twenty-four hours, to 0.045 of a per cent. in three hours." This means that a normal rabbit weighing approximately four pounds is starved for a period of twenty-four hours; the insulin solution is then injected, and three hours later the sugar content of the rabbit's blood is determined. From this datum, the exact strength of the insulin solution is calculated and the solution properly diluted or concentrated to meet the specific requirements of the set standards. Every individual quantity of insulin is thus standardized before it is put on the market for clinical use, and the medical profession is accordingly assured of successful results in its application to diabetic patients.

In spite of the great amount of research work done on insulin, its chemical structure still remains unknown. It is a white powder, containing carbon, hydrogen, oxygen, nitrogen, and possibly sulphur. It appears to be a protein, or at least protein-like in its composition. Its solution responds to many characteristic protein tests, for example, it gives a positive biuret test, a very characteristic test for all proteins. The dry substance is very soluble in water, and can be thrown out of water solution by shaking with charcoal. Finally, it is entirely inactivated by the protein-splitting enzymes, pepsin and trypsin, which occur in the stomach and in the intestine. These and other true protein characteristics are shown by insulin, so that the general opinion is that this substance is a protein of the albumin or globulin type. If insulin is a protein, the hope that chemists will ever be able to synthesize it is very small. It will probably prove impossible even to determine its chemical structure. The chemical structures of the well-known common proteins have never been determined, and no protein has been made synthetically in the laboratory. Insulin, in this respect, is quite different from our other naturally occurring drugs, such as adrenalin for instance, which after its discovery in the adrenal gland was proven to have a definite chemical structure, and is now made synthetically in large quantities.

It has been shown conclusively by the Toronto group and others that the injection of insulin into either the normal or the diabetic animal causes a decrease in the percentage of glucose in the blood. This disappearance may be accounted for in one of two possible ways:

First, the presence of insulin may cause the glucose to change its form or chemical constitution in such a way that it no longer reacts to the methods of blood-sugar analysis which are used.

Second, the presence of insulin may promote the combustion of glucose to carbon dioxide and water, as takes place in the normal animal.

No evidence has been found in support of the former assumption, but abundant experimental data have been obtained to confirm the latter statement. One method of determining and following the combustion of glucose, is to compare the amounts of oxygen consumed and of carbon dioxide evolved. Chemical laws show that for a given quantity of oxygen consumed in the combustion of glucose, there is an equivalent amount of carbon dioxide liberated, in accordance with the following equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O.$$

The ratio $6CO_2/6O_2$ is called the "Respiratory Quotient." If, as appears from the chemical equation, for every given amount of oxygen consumed there is an equivalent amount of carbon dioxide liberated, this ratio will be unity. The respiratory quotient of a normal person is practically unity, which means that the amount of CO_2 and O_2 are equal, thus showing that all the sugar is completely burned.

In a diabetic, however, the amount of CO_2 given off is less than the amount of O_2 consumed, so that the respiratory quotient becomes less than one. After an injection of insulin into a diabetic, the respiratory quotient value increases until in some cases it may even reach the normal value of unity. In all cases, however, the value of the respiratory quotient rises, which is direct evidence that insulin actually controls the combustion of the glucose in the blood.

In the light of our earlier discussion of the chemical and physiological causes of diabetes, one would expect a decrease in the acetone bodies to follow an injection of insulin. This is indeed what happens. By a continual use of insulin the acetone bodies are eliminated from the urine. This fact indicates again that insulin causes the complete combustion of the glucose.

It has been shown also that not only does insulin cause a decrease in the sugar content of the blood of a diabetic, but it also decreases a high sugar content due to other causes. For example, after anæsthetization with ether, or in asphyxia, the content of blood-sugar is abnormally high. A small injection of insulin promptly restores the glucose concentration to normal. In other words, valuable uses for insulin may be found other than that purely for the treatment of diabetes.

The actual method or mechanism by which insulin promotes the combustion of sugar in the blood is unknown.

It is fairly well established that the body tissues have some fundamental part in the reaction. This is shown by the following experiment: if the blood of a rabbit is removed and placed in a test-tube, and a solution of insulin added to it, the sugar is not burned. Also, if the solution of insulin is injected into the animal, and then a sample of his blood is quickly removed and placed in a test-tube, again no lowering of sugar content is detected. It is evident, therefore, that insulin is only active when it is present in the blood and in contact with the muscular tissues of the body.

There is another peculiarity of the action of insulin: it causes the combustion of no other simple sugar except glucose. We have a number of simple sugars resulting from the decomposition of starches in our foods. But, as has been noted in an earlier paragraph, these simple sugars in passing through the liver were changed to the one sugar, glucose. The liver, therefore, aids the subsequent action of insulin by forming the only sugar which insulin has any action upon. This coöperation between the liver and the pancreas is one of the many instances where two organs, seemingly with no connection to each other, are nevertheless closely related in the body processes.

Insulin cannot be regarded as a cure for diabetes in the usual sense of the word, but it enables the diabetic patient to utilize carbohydrates in the normal manner, thus giving his own pancreas a chance to regain its normal strength and vitality. Whether or not the use of insulin over a considerable period of time will give the pancreas the necessary chance to recuperate and thus function properly again, is a debated question, unanswerable at the present time because the general practice of insulin treatment is so very recent. It is entirely possible that in mild cases of diabetes a constant use of insulin may allow this to take place, and the patient may eventually be cured. In very severe cases it is probable that the pancreas has degenerated to such an extent as to be incapable of rejuvenation.

Insulin treatment cannot replace dietetic treatment. Where insulin is used, however, the calorific value of the diet may be much greater than it could be without its use. Roughly, the minimum calorific value of the diet for an individual at rest is fifteen calories per pound body weight. With the use of insulin, even in quite severe cases, the calorific value may be increased to such an extent that the patient may resume work.

The most brilliant results with insulin have been in the treatment of diabetic coma. When the patient is in this condition, large doses of insulin, from fifty to a hundred units, combined with an adequate amount of pure glucose, are injected directly into the blood-stream. In all cases of coma reported by the Toronto group, which have not been complicated by other factors, the patient's life has been saved by this treatment.

Up to the time of the discovery of insulin it was fatal to perform a surgical operation on a diabetic patient, due to the great increase in the blood-sugar content caused by the use of a general anæsthetic like ether. Now, surgery may be resorted to with comparative safety if the patient is given a large dose of insulin before administering the anæsthetic.

Except in very severe cases of diabetes, or in diabetic coma, the patient is taught to take care of his own daily insulin injection and his diet, as it is obviously impossible for the physician to be present to administer to the patient every dose of insulin required by him during the day. After diabetes is detected the patient is placed in a hospital where his diet is carefully balanced for him, and the daily injections of insulin given. His case is carefully studied, and he is taught the nature of his ailment and how to care for himself. The patient is generally kept in the hospital from two to four weeks, during which time the best diet and the proper dosage of insulin are determined for his individual case. He is then discharged and is now able to care for his own diet and to administer his own insulin dosage under the supervision of his physician. Several authorities on the treatment of diabetes have stated that comparatively little trouble has been experienced by the medical profession in allowing their patients to look after their own welfare.

Most of the mild cases require from ten to twenty units of insulin daily. At two cents a unit, this is a remarkably small sum to be expended for the comfort and pleasure which diabetics may enjoy in eating a wholesome and appetizing meal without fear of the results. Insulin is injected subcutaneously with a hypodermic needle, either one, two, or three times daily in definite relation to the meals. Best results are obtained if the injection is made from one-quarter to one-half hour before meal-time. The effect of a dose of insulin lasts, in general, about six hours, which insures the complete combustion of the carbohydrates of the diet during the periods between meals. It is unfortunate that insulin cannot be taken orally, for this method would eliminate the use of hypodermic injection. The nature of the drug prohibits oral administration, since it is protein in character, and would be inactivated by the protein-splitting enzymes of the stomach and intestine before it had a chance to function in the blood. Other methods of administration have been tried with negative results.

There is one grave danger liable to result from insulin treatment. An overdose of insulin will cause the blood-sugar content to drop considerably below the normal level of 0.1 per cent. When the sugar content falls to 0.06 or 0.07 per cent. the patient suddenly feels very weak and restless. On further decrease of the sugar, intense sweating, delirium, unconsciousness, and even death may follow. This condition may be quickly remedied by the administration of some form of carbohydrate food. In the early stages of this condition, relief may be obtained by administering cane sugar or corn syrup by mouth. If the patient is delirious or unconscious, pure glucose must be injected directly into the blood stream in order to save his life.

Due to the fact that the use of insulin in modern medicine is very recent, many of our leading universities and medical schools have started courses in the use of insulin for the practising physician, which are being well attended. Continued research on the preparation, action, and chemical composition of insulin is being carried on, especially at the University of Toronto, and the Medical School of St. Louis. It is estimated that there are some eighteen thousand persons in the United States alone that are now taking insulin treatment.

The brightest spot in the whole story of insulin is the attitude that Dr. Banting and his associates took toward the giving of insulin to the world. Had they been mercenary men, they could have made unlimited wealth by selling their patents or by selling their product at a high price. But they were not mercenary men, and refusing to entertain any idea of material gain to themselves, they arranged (in the manner outlined above) for the production and distribution of insulin at cost price. It would seem therefore, to be all the more appropriate that these men should have received the award of the Nobel Prize in Medicine for 1922, and the sum of forty thousand dollars which accompanies the award. Moreover, while the Nobel prize was originally awarded to Drs. Banting and McLeod, these gentlemen have generously shared both the honour and the money with their associates, Dr. Collip and Mr. Best. In the meantime the Canadian Government has provided in its civil list an annuity of seven thousand five hundred dollars a year for Dr. Banting, while the Ontario provincial government has made an appropriation of ten thousand dollars for the Banting-Best Chair for Medical Research, of which Dr. Banting is the first occupant.

Dr. Banting is thirty-two years old. He was born and raised in Ontario, and graduated from the medical school of the University of Toronto. He served overseas during the war as battalion doctor with the rank of captain, and was awarded the Military Cross for bravery.

This is a very brief outline of the discovery and use of insulin. I have endeavored to present some of the peculiarities of diabetes, both from a chemical and a physiological standpoint; the events leading to the discovery and preparation of insulin; and finally, some aspects of its use by the medical profession. In conclusion, I desire to thank the Insulin Committee of Toronto for so kindly sending me some of the information and data contained in this paper.

Henry O. Nicholas

III

ANIMAL BEHAVIOR AND THE PHYSIOLOGY OF THE NERVOUS SYSTEM

WHEN you see a moth fly towards the light, or a cockroach flee at your approach, you naturally assume that the animal has the same sort of feelings about the matter as yourself—the moth goes to the light out of curiosity or because it likes the light, and the cockroach realizes the danger and seeks safety in flight. But you really cannot be sure what the animal's feelings are; possibly there is not much of anything in the minds of these insects and other low forms of life. We must try first to explain their behavior without assuming human-like motives, for such an explanation would be simpler and therefore preferable to one that made unnecessary assumptions.

Insects do, in fact, behave in a very mechanical manner. Take the case of the moth. It has been found that the force with which a moth's wings beat is directly proportional to the intensity of the light that strikes the moth's eyes. Further, if just one eye is struck by the light (say the other is blackened), then the wing on the opposite side of the body does the beating; the wing on the same side beats feebly or not at all. If now, a moth is not headed directly for the light, one wing beats harder than the other, because one eye is in the shadow of the animal's own head and the other is not. The unequal beating of the wings causes the moth to turn, just as a boat would if one oar were pulled harder than the other. The moth continues to turn until both eyes receive the same amount of light, but the eyes are equally illuminated only when the moth is headed directly for the light. Both wings now beat with equal force, there is no further cause for turning, and since the moth is headed towards the light, its flight carries it towards the lamp from which the light is coming.

That the explanation just given is correct can be proved very simply. A moth, placed in a box which is uniformly illuminated from all sides, does not move in any particular direction, because both eyes are receiving the same amount of light; but if one eye is blackened so that the other eye constantly receives more light, then one wing beats harder than the other and the moth flies in circles.

It is obvious from this last experiment that the moth does not move to the light out of curiosity or from love of the light. A human being would find one eye about as useful as two in satisfying his curiosity, and when he got to the light, his behavior would not necessarily be different whether he possessed both eyes or just one.

The mechanical behavior of the sort just described for the moth can be well shown in connection with certain very small animals known as Paramecia. These are not very familiar animals on account of their microscopic dimensions. You might drink a glass of water without knowing that you were swallowing millions of Paramecia or even suspecting that there was anything unusual about the water apart from the fact that it was got from a slightly stagnant pond. In order to see the Paramecia you would have to examine a drop of water under a microscope. You would then see that they lacked a nervous system, and in general that they had a very simple structure. You would be struck first of all by their smooth, gliding motion through the water, in spite of the apparent lack of swimming organs; but if you examined a Paramecium very closely you would notice on its surface a covering of minute processes shaped like hairs, or rather like eyelashes, and known as cilia, and you would see that the cilia were constantly beating and causing the Paramecia to move.

Paramecia ordinarily swim about in all directions; but let us pass an electric current through the water, and see what happens. To do this, we insert wires from an ordinary dry battery into a drop of water that contains the Paramecia. By means of a key the electric circuit can be made or broken at will. So let us close the circuit. Immediately all the Paramecia move in the direction of the current and migrate towards the end of one of the wires connected with the battery, in particular, the wire connected with the negative pole of the battery. If the current continues long enough the Paramecia collect about the wire just as moths do about a light, and for a similar reason. Briefly stated, the reaction depends upon the fact that negative electricity reverses the beating movements of the cilia. With this simple fact in mind, let us analyze the reaction. We will begin with the Paramecia swimming in all directions. Let us focus our attention on an individual that is not headed directly for the negative pole so that one side of the animal is more or less facing this pole, and the other side is not. If we will think of negative electricity as issuing from the negative pole in straight lines very much as light does from any source, then we may regard one side of the Paramecium as in the shadow, as it were, of its own body, and on this side the cilia beat as usual. But on the side exposed to the negative electricity, their beating movements are reversed. This reversal of the cilia causes a turning movement, again very much like the turning movement of a boat when a person pulls on one oar and backs water with the other. The turning movement of Paramecium will continue until the long axis of the animal is parallel to the direction of the current. Now equal numbers of cilia on both sides are reversed. Moreover, only a few of the cilia at the front end are reversed; those farther back are not exposed to the negative pole, because of the animal's shape. There is now no further cause for turning, and Paramecium moves straight for the negative pole.

Note, now, that the reactions of both the moth and the Paramecium have very much in common. Both animals come to be fixed in such a position that the length of their bodies corresponds to the direction of the light or electricity, as the case may be. Or, to state the matter in another way, the body of the animal becomes oriented in such a manner that its long axis is parallel to the direction of the stimulus. This orientation is brought about automatically because the body, so long as it is not parallel to the direction of the stimulus, is more strongly influenced on one side than on the other, and a turning movement results. A mechanical response of this nature is known as a tropism.

Many of the apparently intelligent responses of insects and other lower animals are probably of a purely mechanical nature. You spy a cockroach on the wall with evil and evident intention, and the little beast makes a hasty retreat to some crevice; he seems to show all the outward evidence of fear and excitement, and of a conscious purpose to reach cover. But it is possible that we are reading all of these mental states into responses which are purely mechanical, just as we do when we say the moth goes to the light out of curiosity.

Insects get into cracks and crevices probably not because they are consciously aware of the protection afforded, but because contact of one portion of the body with any solid object tends to result in movements such that more of the body comes into contact with the surface, and the movements continue until a maximum surface of the body is in contact with the solid surface—and then the animal is in the crevice. This is simply another form of tropism. Furthermore, many insects do not go towards the light but away from it; the reaction is again a tropism with connections between eye and muscles the reverse of those mentioned for the moth. As crevices and cracks are usually dark, it is easy to see how the insect might go towards them in accordance with the tropism in question; and once he arrives at a crevice and touches it with his body, another tropism (involving response to contact with solid surfaces) carries him into it.

The insect does not really move to the crack with the object in mind of getting in and being protected. He gets there for one reason, and gets in for another; and the reason in both cases is in the nature of an automatic response.

Much has been written regarding the remarkable behavior of bees and ants, and their supposed powers of reasoning. A consideration of just one or two cases will suffice as examples. Ants will build a bridge across any water that is in their nest and that encircles their young, and come to their rescue. The bridge is built by piling up particles of dirt in the water. Here we have something that looks on its face very much like reasoning, but it is in fact merely a particular expression of a more general instinctive reaction which consists in covering up any debris or other material which the ants cannot remove from their nest. They build the bridge across the water even if there are no young to be rescued. That ants do not know enough to build bridges in order to attain some objective, can be shown by a simple experiment. Honey, of which the ants are very fond, is placed within easy reach of them in a dish. If now the dish is suspended by a string and raised slightly from the ground, say a third of an inch, so as to be inaccessible directly, the ants fail to get it; they do not build up a little mound of earth from which they might readily climb on the dish.

One of the things that have attracted attention in connection with ants is their capacity for communication. An ant which has found a supply of food soon returns to it with others; but she probably has no mysterious powers of communication by means of which she can describe to the others the location of the food supply. This can be shown by the fact that the ants cannot locate the supply if they are separated from the one that discovered it while they are on their journey to the supply. They must be led. But what caused them to leave the nest and follow? Ants are said to stroke each other with their feelers, and in this way, it is believed, they communicate. A certain kind of stroking means "follow me"; or, perhaps it would be better to say when an ant is stroked in a certain way by another, it automatically follows the latter. And the act of stroking may simply be an automatic response which an ant gives upon returning to its nest, after having come across a supply of food.

Of the numerous other cases of behavior which seem to involve the power of reasoning in the insects, only one other need be mentioned. A certain wasp, Ammophilia, which digs its nest in the ground, has been observed to seize a small stone in its jaws and use it to pound the loose soil with which it had filled up the hole to the nest. Now this appears at first sight like a close approach to reason, in that it involves the use of a tool. But is it really necessary to assume that there is involved here any radical departure from the insect's instinctive behavior? The act of lifting up small stones in its jaws, and the act of packing in dirt, are parts of the instinctive process of filling the hole to the nest. The wasp, in occasionally using a pebble in packing the dirt, is simply combining two acts normally involved in the nest-building instinct.

When we come to consider the higher animals, we find, together with greater brain development, greater freedom and variety of action. A moth butts its head against a lamp, no matter how many times it has previously done so. In contrast to this a higher animal has the capacity readily to modify its behavior in the light of experience. A child associates the pain involved in touching a flame with the sight of the flame, and it does not repeat, at least not very often, its first act of inexperience. Some connection has been made in the child's brain between the part involved in seeing the flame, and the part involved in feeling the pain, a connection which is referred to as association and which is at the basis of the learning process.

The power of association resides in the fore part of the brain (the part just back of the forehead). You naturally look to the structure of the brain for an indication as to how it works. If you examined a thin slice of the brain through a microscope, your first impression would be a confused mass of threads, but on closer inspection you could discover some order out of the apparent confusion. You would see numerous connecting units—millions of them in the brain as a whole—each resembling somewhat a minute uprooted plant with a main trunk and side branches and with several roots springing from a slightly enlarged bulb-like base. These are the neurones. They may be arranged simply end-to-end like the cars of a freight train, a "trunk" of one neurone ending near a "root" of the neurone next ahead; but as a rule the side branches make additional connections with other neurones. The adjacent neurones are, like the cars of the freight train, separated by a small gap, which, in the learning process, is somehow bridged over; and in this way originally separated parts of the brain are brought into communication with each other; that is, through the process of association.

The number of neurones in your brain was established at birth. Learning does not involve any increase in their number; it involves only the making of new connections between them. When you forget something, the "bridges" between certain neurones have been broken down and the small gaps again intervene.

A certain biologist conducted experiments on dogs to test their powers of association. We all know that dogs can learn and therefore have the power of association, but the biologist referred to was interested in precise information on the subject. He found that a dog could be made to associate almost anything with food, for example, the sound of a bell, or the scratching of a certain area of his skin. All that was necessary was to sound the bell (if this was involved in the connection sought) on repeated occasions when the food was presented to him. If now the bell was sounded, the dog's mouth watered even if no food were presented, showing that the dog had formed the association. In a similar way, the dog's mouth might be made to water by simply scratching a certain area of his skin. Moreover, the dog could make fine distinctions. If he had been taught to respond to a note of a hundred vibrations per second (as shown by his mouth watering), one of ninety-six per second called forth no response; or, if the scratching of a particular skin area had been made the signal for food, a slightly removed adjacent area could not be substituted. A curious fact came out in connection with these experiments. If there were removed from a dog's brain a certain area through which an association was known to take place, the signal for the presentation of food, say sounding of the bell, did not call forth in such a dog the usual response, namely, watering of the mouth, but instead the dog became drowsy and gradually went to sleep. The result is explained by a certain process which occurs in the normal animal, as well as the one operated on. When the dog hears the sound of the bell, he concentrates his mind on the idea of food. This concentration implies a suppression of all other mental activities; to use the technical term, there is an "inhibition" of activity in all parts of the brain except the area concerned with the association. If this area is removed, inhibition occurs just as before, when the bell is sounded, and since the area is now missing to which all mental activity would be restricted, the dog simply becomes drowsy and goes to sleep.

Our simplest thoughts and mental states involve the organized activity of at least thousands of neurones, possibly of millions. In dreams, the connections between the neurones are haphazard and disorganized. The process of inhibition is not in full swing, and the activity of the brain is not limited to a well coördinated set of neurones. There result the freakish connections characteristic of dreams. In hypnosis, there are lacking the usual inhibitions to suggestion, for which reason a suggested idea, thought, or action automatically goes into effect. Hypnosis is essentially an exaggerated state of susceptibility to suggestion. We are all normally more or less hypnotized, depending upon the extent to which we are susceptible to suggestion.

To the layman in psychology some of the things that have been written about the subconscious seem to exaggerate the aspect of mystery ascribed to it. We do some things subconsciously, but there is no more mystery about this than that we should be unaware of some habitual act, such as walking. Any act, if sufficiently often repeated, tends to become habitual, and drops out of the field of attention, although at first it may have involved a great mental strain; witness a child's attempts at walking or writing. Certain simple mental processes, if sufficiently often repeated, may also become habitual and drop out of the field of attention, and then you would regard them as "subconscious." I can readily conceive, for example, that a bank clerk might be adding up figures without thinking especially of what he is doing; in fact, his thoughts might be on something else, and in this case he would be adding subconsciously. It was inevitable, however, that much of the speculation springing up in connection with psychoanalysis and the subconscious should run wild, but psychologists, with occasional help on the part of biologists, may be confidently expected to set this new house in order.

Many of the apparently intelligent acts of animals are achieved in an accidental manner. This fact is indicated by certain experiments. Dogs were confronted with the problem of getting to some food from a cage, from which they could escape only after pressing a lever and opening the door to the cage. An inexperienced dog never went directly to the lever and pressed it. What he usually did was to nose and claw impatiently about the cage until by accident he struck the lever and was released. When confronted with the problem the second time, he did not approach the lever and make his escape directly, but he scrambled about again, this time, however, more or less in the part of the cage where he had met with success on the first occasion, and as a result the number of fruitless efforts was reduced. On the third occasion there was a still further reduction in the number of errors, and so on, until eventually just the right move was made. This sort of behavior is generally referred to as "trial and error." Many attempts are made, one succeeds by accident. The dog who sees his master open a gate does not reason, "Master has opened the gate by pressing the latch, therefore I should be able to open it in the same way." He does not even imitate his master in a blind way. He learns to open it very much in the same way as the dog did in learning to escape from the cage—by the method of trial and error.

When students of animal behavior first learned these facts, there was a tendency for some of them to take the stand that lower animals were entirely without powers of reasoning, that it was man alone who had this faculty, and that there was a big gap, therefore, between man and any lower animal in this regard. In taking this attitude, they were probably going to extremes. They forgot that many of the reasoned acts of man himself were based on the method of trial and error. You are given a puzzle to put together. You do not simply size up the situation and arrive directly at the solution. What you normally do is to manipulate the puzzle; you make a good many tries, most of them failures, but you are guided by them, just as the dog was, and finally you get the thing. Even the higher forms of reasoning, which apparently are pure abstraction, involve this method of trial and error. When you are confronted with a problem in mathematics, supposing now you are good at this sort of thing, you do not as a rule simply set your mental machinery into operation and arrive directly at the solution. You first make what amounts to a number of guesses, you try this and that possibility, and you finally hit upon one that leads to a result. The difference between a person who is good at mathematics, and the rest of us, is that the mathematician makes fewer irrelevant guesses than we, and he eliminates them more rapidly. When the dog learns to open the gate, this is the very process he goes through, but the whole thing is cruder and on a simpler basis. To be sure, the animal almost certainly does not go through a reasoning process that is consciously guided, such as when we reason that if A is greater than B, and B is greater than C, A is greater than C. But even men seldom use consciously this syllogistic form of reasoning. Once a problem has been got to the point that it can be put in the form of a syllogism, it is regarded as solved; the real difficulty consists in finding the proper clues to its solution, and this involves the making of guesses, as a rule. Reasoning by no means resolves itself entirely into a process of trial and error, but this process is an important element in the situation, and it has its crude beginnings in the animal mind.

One of the outstanding features of human behavior is the use that man makes of means to attain an end. This is especially evident in his use of tools. A machine is merely the outcome of a highly developed tool; the firearm, the printing press, locomotive engine, aeroplane, telephone, radio, all these and many others are really machines in the broader sense of the term. It is obvious that man owes his superiority over all other animals in large measure to his use of machinery.

To what extent do we find lower animals resorting to the use of tools, and adapting means to end? We naturally look to the monkeys and apes for manifestations of reasoning power, because these animals approach man more closely than do all others in regard to brain size and structure. Monkeys have, in fact, been observed to use sticks and other objects as tools. For example, if food is placed beyond the reach of a chained monkey, he will use a stick with which to rake it in. This, to be sure, is a very simple act, but you would hardly expect a dog or cat to make use of a tool in even this simple fashion, even allowing for physical limitations. The apes are among the few animals that agree with man in their capacity to use tools. Now, when we look for the cause of this, we naturally emphasize the matter of brain size; but there is another factor of importance which enters in. I refer to the development of the hand. It seldom occurs to us how much of our mental development we owe to the hand and its manipulative powers. There is a constant interaction taking place between the hand and the brain. The mere handling of an object imparts information as regards its nature and, moreover, the information so gained tends to increase manipulatory skill and leads to the use of the object as a tool. The whole theory of manual training is based on this fact; it involves a conscious attempt to approach the brain through the hand. In the process of evolution, a highly developed brain without nimble fingers to carry out its commands would have been useless; and on the other hand highly developed fingers without the brain to direct them would have been equally useless. There probably was, therefore, a constant interaction between the two in the course of racial development; progress in one was made possible by progress in the other. Other important factors, to be sure, were involved in man's mental evolution, especially his use of language and his social organization; but the development of the hand as a prehensile organ ought certainly to be included in the list, for it is in this connection that man became a tool-using creature, a creature who learned to attain his ends not just by tooth and nail, but by indirect means that were often much more effective.

In its general outline and operation, the nervous system is simple enough. You touch a hot stove, and automatically you withdraw your hand. One nerve conveyed the message from skin to spinal cord, another carried the message to the muscles which moved your arm. The spinal cord brought about the connection between incoming and outgoing message. I say that the connections were made through the spinal cord rather than through the higher brain centres because the feeling of pain is not necessary for this reaction. You would give very much the same reaction if your hand were burnt while you were asleep, and before you actually woke up and realized you were burnt. You have probably noticed that a person will withdraw his leg if the sole of his foot is tickled while he is in deep sleep and totally insensitive. This sort of response is of the simplest kind possible through the nervous system; it involves no act of will or reasoning. Other reactions of the same automatic nature are given when our eyes are touched and we wink, or when something in the throat causes coughing. These are all known as reflex acts. The connections which they involve through the spinal cord or lower brain centres are established at birth. The more complicated forms of behavior take place through the higher brain centres and depend upon connections which are made after birth, in the process of learning. They involve the hitching up of neurones originally not connected, and when behavior takes place through these complicated and new channels we refer to it as action based on reason or thought. In a reasoned act there are involved typically the same elements of nervous conduction as in the reflex act, a central part connecting incoming and outgoing messages; but in a reasoned act the central part of the process is long drawn out. Behavior, in other words, is a more general process that includes thought as one of its elements.

Reasoning, according to the view just presented, is closely connected with action. In fact, practically all of our mental processes are. The mind evolved in connection with action, for it was only in action that the mind could prove its usefulness. An individual who could foresee danger and avoid it obviously had an advantage over one who lacked this capacity; and in many other ways action became more effective under mental guidance. During the evolution of the race, and in the free state of competition under which it took place, those who lacked intelligence succumbed to those who had wits, and those who had wits succumbed to those who had more wits. In this way the mind gradually progressed under the influence of natural selection, from crude beginnings to its present high state of development. But all the while, the mind was primarily the tool to action. It was only in connection with action that the mind could justify its existence and come under the guiding influence of natural selection.

The origins of human behavior are discernible in the behavior of the lower animals. The difference between the two is in most respects a matter of degree, not of kind. But in one respect there does seem to be a genuine difference between them. Among the lower animals we do not find the more elevated forms of behavior that we designate as moral. Man seems to be exceptional in this regard. It was for this reason that moral philosophers of the eighteenth century postulated a certain faculty which was to be found only in man, and which they designated as the moral faculty or conscience. They claimed it was unanalyzable;

it was an unresolvable entity—a faculty, and that was all there was to the matter. Developments in the field of psychology have, however, shed new light on this problem. Present-day students of psychology and animal behavior make no attempt to deny the existence of a conscience and of the more elevated forms of behavior. Conscience and moral behavior are as real to-day as ever, but what these students have attempted to do is to analyze moral behavior, and to find out the simpler elements of which it is made. In so doing they have pointed out two things: first, the instinctive nature of all voluntary acts; and second, man's social nature.

An instinct has often been defined as a spring to action; the force from behind that is the basis of our desires and directs our acts into certain channels—witness the difference in the behavior of your husband before his hunger has been satisfied and after. If there are obstacles in the way of satisfying an instinct, a long train of reactions may be set up. A hungry person, without food or money with which to buy it, thinks of ways and means to satisfy his desire; he may try to earn the necessary money, or he may hit upon the happy expedient of dropping in at a friend's house for dinner. In any case, the long train of reactions through which he goes was determined by his desire for food. In this sense, the instinct is the urge—the spring to action.

The term "instinct" usually calls to mind the instincts of hunger and sex; but we must not overlook the existence of other important instincts, among them fear, or the urge to escape destruction; and anger, the urge to overcome persons and things that are obstacles to the free expression of other instincts. These, to be sure, are all instincts that suggest our animal nature, but without them neither the individual nor the race could continue its existence. It was precisely these matters that were of prime importance during our evolution, and it was about them that behavior shaped itself.

One of the instincts that always arouses our admiration, whether we see it expressed in man or in lower animals, is the love of the mother for her young, the urge to protect, caress, and nourish them. This maternal instinct is more strongly developed in the female but by no means lacking in the male. It is this instinct that urges us to protect the weak in general, and it is because of its stronger development in the female that women are more active than men in all forms of philanthropic and charitable undertakings. In the male it is aroused, especially during the period of courtship, by the female, and it converts the mere sex attraction into the more elevated and enduring form of love. It is this instinct, also, which is outraged by mistreatment of the weak, especially of children, and is at the root of our feeling of righteous indignation. The maternal instinct certainly must be taken into account in considering many forms of moral behavior.

Now the maternal instinct by itself would not suffice to account for the whole of moral action. Other facts have to be taken into consideration, and there is one fact in particular that is of especial importance; I refer to man's social nature. In regard to his social nature man occupies a unique position in the animal kingdom. In most other species an individual can, after a longer or shorter period of infancy and dependency, shift for itself and lead an almost isolated existence. But for man this would be an almost unthinkable state. He would be changed from the most powerful of all creatures to one of the weakest, from a thinking being with the power of language, to one whose mental furniture consisted almost entirely of his immediate bodily wants. His acts would be neither moral nor immoral; they would be non-moral. It is only in coming into contact with others that a child soon learns that some of his acts meet with approval and others with disapproval. Accordingly, he comes to set up certain standards of right and wrong, and his behavior becomes modified accordingly. To be sure, he has not yet achieved the highest plane of social conduct, but he is on the way. Moreover, it is only in coming into contact with others that the child distinguishes between himself and others. If he were entirely isolated, there would be no occasion for such a distinction; he would not think of himself as an individual distinct from others. The concept of self, therefore, depends, in its development, upon social contact. Without this concept, the sense of responsibility and moral behavior would be impossible.

Now, there is dependent upon the concept of self the expression of two instincts, one characterized by an emotion known as positive self-feeling, the other by the emotion, negative self-feeling. These instincts may be aroused in a large variety of ways. Very commonly praise, if it is properly dished out, arouses in us our positive self-feeling; but praise is by no means the only stimulus for this instinct. When, for example, a proud father tells you how clever his children are, he is really boosting himself, for he identifies his children with himself, and they arouse his positive self-feeling. A work of art arouses in the artist his positive self-feeling; the act of creating in general does, entirely apart from the praise of others. The instinct characterized by negative self-feeling is just the opposite in its effect to the one characterized by positive self-feeling. These two instincts are very important in their bearing on moral behavior. As the individual gains in maturity, his instincts in general become harmoniously organized about certain ideals of behavior, ideals which become so firmly ingrained in him that he comes to identify them with himself; and as a result, any course of conduct which conforms to the ideal arouses in him his positive self-feeling, and any course which defeats it arouses his negative self-feeling. The foundations are now laid for the more elevated forms of conduct.

This analysis makes no attempt at completeness, but I hope it will at least suggest that no adequate account of moral behavior can ignore man's instinctive make-up and his social nature.

EDGAR ALTENBURG

IV

CIVILIZATION AND THE MOTOR CAR

MOST of us join King David in believing that "the days of our years are three score years and ten; and if by reason of strength they be four score years, yet is their strength labor and sorrow; for it is soon cut off, and we fly away." In consequence, we try to crowd into our active years a maximum of those pleasures which attract us most. In this attempt, many of us are hampered seriously by the necessity of providing a living; but there are others more favored by fortune who find much of their joy in life in performing well, labors which poorer men would avoid if possible. In either case, since the effectiveness of our work has such an important bearing on our happiness, any time-saving or labor-saving invention of general application cannot fail to cause extensive changes in our daily lives. Any one could easily cite numerous examples in verification of this statement; but perhaps not every one has noticed that practically all of these inventions appeared either with the dawn of history or else within the last two hundred years. This fact is worthy of some attention.

During the thousands of years composing the history of man before the eighteenth century of our era, his regular daily life had varied only a little from century to century. Living conditions improved somewhat, it is true; but to persons living in the twentieth century, general changes in the life of the masses seem slow indeed until a century and a half ago. Before that date, all work was confined to what could be accomplished by human or animal energy or by wind or water power. Facilities for travel or transportation were limited and uncertain; health and life itself were precarious; leisure and opportunities for education were the privileges of comparatively few people. For the majority of mankind, strenuous efforts were required simply to exist.

But almost coincident with the French Revolution, there began a change in industrial life as radical, as rapid, and as extensive in its effects as were the political changes of those days. In fact, historians commonly call it "The Industrial Revolution". It marks the beginning of a stage in human progress which future historians may well call the "Age of Power", for without mechanical power the industrial revolution would never have occurred; without power our present type of civilization could not have been attained; and without power we cannot imagine it continuing.

It was about 1770 that men began to learn how to control the steam engine, that gigantic slave of the nineteenth century whose labor-saving capacity was certainly one of the most potent forces moulding life during that period. Once men were able to secure mechanical energy from fuel, they could make widespread application of machines which lightened the daily burdens of countless workers. In proportion to the effect of these machines on the labor of men, the life of the world was altered. The daily working hours of industrial employees decreased from twelve or fourteen to ten, then to nine, then to eight, with even further decreases in prospect. The application of power to spinning, weaving, knitting, and sewing machines released millions of women and children from the drudgery of clothing manufacture—certainly the first step toward the general political freedom of women. Locomotives and steamships made possible both extended travel and commerce and the settlement of productive new countries. And, when chemical or physical science pointed the way to new materials or new processes, mechanical energy for the work was available in constantly increasing quantities and at a price which made progress possible economically as well as theoretically.

In the past fifty years especially, progress in the application of power has continued at a bewilderingly rapid pace—a pace which seems to grow faster and faster. We have hardly time to learn the workings of one new device before our children are embarrassing us by questions on the operation of an improvement. Not only is this development extremely rapid, but its effects are experienced in all walks of life and in all parts of the world.

It would be hard to determine which type of power application has grown most rapidly or most widely; but excellent examples of such development may certainly be found in transportation—a field of activity which affects every aspect of our modern civilization. Since few of us come in close contact with steam railroad equipment, its progress has continued almost unnoticed. But with the development of the electric motor and the internal combustion engine we are more familiar. If they are not already installed in our houses or back yards, we meet them in some form every day. In the past fifty years of their life, these two younger brothers of the steam engine slave have raced so rapidly over the country, have quarreled so loudly, and have changed so many details in our daily lives that the most casual observer could not fail to notice their growth in usefulness. The combined effects of these two agencies have been especially striking in the field of city passenger transportation.

Forty years ago, transportation facilities for city dwellers were very little better than those enjoyed by the ancients. Street railroads existed, it is true; and the development of cheap steel for springs had made possible comfort for which kings must have sighed years ago; but as a means of motive power, the horse was still supreme. In two score years, this supremacy has been entirely lost. In spite of their centuries of use, horse-drawn vehicles have been very largely forced off of our city streets by successive attacks from cable cars, electric surface cars, elevated railways, subways, and finally automobile busses, taxis, and jitneys.

What became of those displaced horses? Were they perhaps absorbed by the rural districts? The census figures show they were not; in fact, the farms not only did not accept the city's horses, but actually substituted tractors, automobiles, and interurban railroads for their own animals. Between 1914 and 1923 the number of horses in cities decreased forty-six per cent.; but during the same period, the numbers in the country also decreased ten per cent. Over the whole nation, the number of horses decreased two millions, although the number of cattle increased ten millions in the same period. The value of horses decreased forty-two per cent. during a time when the value of other forms of livestock increased substantially.

As horses wore out, they were simply replaced by machinery fed with electricity or liquid fuels, thus making soil previously devoted to forage crops available for raising food for men. Since the produce from several acres is required to feed a working horse for a year, it is interesting although not pleasant to speculate on what the cost of living would be to-day if we had to feed with corn and hay the horsepower required by our electric and gasoline vehicles.

These two forms of transportation were also largely responsible for the recent growth of our cities through the development of suburbs. Many of these additions could never have been served adequately by steam or animal motive power alone; but when electricity and gasoline made available cheap, quick, and clean suburban transportation, the man with a moderate income could move to the city, enjoy its facilities, and at the same time experience the freedom and health of the small town. Even the people living in the crowded parts of the city profited, because the decrease in the numbers of horses stabled near humans greatly simplified problems of health and cleanliness.

But there is one effect of this change to mechanical transportation which, though freely prophesied, has not yet come to pass. Although the number of horses we raise is steadily diminishing, the United States is still able to develop champion racehorses; and although the internal combustion engine has provided us with many thrilling spectacles in the shape of contests between speed-boats, aeroplanes, motorcycles, and automobiles, horse races still attract large crowds of enthusiasts.

This victory over the horse was won by electric and gasoline transportation acting together, and it would be difficult to say which of the two was the more responsible for changes in city life in the past forty years. But in the case of rural life, no such difficulty appears. The major part of the world's population still lives in districts far removed from supplies of cheap electricity, although easily accessible to wheeled vehicles. In such localities, the ability of the automobile to carry its own supply of energy gives it an insurmountable advantage over the electric machine.

Even the comparatively independent trolley busses or trackless trolleys, now operating in eight American cities, cannot leave their wires far behind, for we have not yet been able to produce electricity in a sufficiently concentrated form for propelling automobiles. Storage batteries require careful attention, and by their weight and bulk they seriously limit the speed, capacity, and range of action of automobiles. Gasoline, however, carries energy in a very concentrated form. If we imagine an automobile which can make twenty miles on a gallon of gasoline drawing this fuel through the carburetor in a circular jet of liquid twenty miles long, the diameter of this thread would be only three and one-half thousandths of an inch. Gasoline contains sixty per cent. more energy than an equal weight of coal, and the apparatus for liberating this energy is surprisingly light and compact.

Because the gasoline automobile can go wherever roads exist, carrying its own supply of fuel, and because it is cheap, powerful, speedy, reliable, and easily handled, it has caused very serious changes, both good and bad, in our physical surroundings, habits, morals, international relations, and in a score of other ways. Because of the extent and rapidity of these changes, they require recognition and control.

In no country are these changes so noticeable as in the United States. Although the automobile was first manufactured in quantities in France, ninety per cent. of the world's supply is now produced in America. Last year we built more than four million vehicles—fifty per cent. more than in 1922. This year we shall probably make five million cars—an increase of twenty-five per cent. Last year the products of the automobile and tire industry were valued at five billion dollars; this year the figure will probably be seven billions. The production of so much wealth of this sort cannot fail to have serious effects on our lives. For one thing, the manufacture of automobiles, tires, and accessories furnishes employment for two and three-quarter million American workers. This number increases to three and a half or four millions if we include chauffeurs, oil refinery workers, and the men engaged in constructing buildings and in supplying materials for automobiles. From these feeder industries, the new automobiles alone require two and a half million tons of steel annually, while the whole automobile industry in all its branches consumes six million tons annually—a quantity which is about ten per cent. of our total steel production and is equivalent to more than half the output of England. Automobiles in California carry in license plates alone about five hundred tons of steel. Twenty-five per cent. of our aluminum and fifty-four per cent. of our upholstery leather goes into motor cars. Windshields and windows require thirty-six per cent. of our plate-glass supply.

But Americans do more than monopolize the manufacture of automobiles. They keep most of them for their own use. Nowhere else in the world are there so many automobiles, either in total numbers or per capita. There exist in the world to-day something like seventeen million automobiles and trucks, of which over fifteen millions, or eighty-nine per cent., are registered in the United States. The whole continent of Europe contains only about one and a half million, or about nine per cent. of the world's supply. The United Kingdom, which is the second country in the world and the first in Europe in point of number of motor cars, contains less than seven hundred thousand vehicles, or a trifle more than the number registered in Texas and about half the number registered in New York State.

In Great Britain, there is one automobile to a hundred people; in Texas the ratio is about one to nine; in the United States it is one to seven; in California it is one to four.

Because America contains such a very large proportion of existing automobiles, we should be careful not to expect in other countries changes which are general in the United States. And in predicting future changes due to the automobile, we must remember that opportunities for change may differ in old countries and in new ones like America.

For example, one of the effects of the motor car most noticeable in this country is our extensive and costly programme of highway improvement. On the continent, development of this character has not been marked lately because many existing highways have proved satisfactory for the amount of motor traffic they carry. The foundations of their highways are old and firm, and their drainage and maintenance systems are the envy of American engineers. Excellent national highway systems have existed in Europe for many years; but in America we did not have even one good transcontinental road before 1913. In that year, we began in earnest to build the thirty-three hundred mile Lincoln Highway between New York and San Francisco.

As soon as the cheap automobile became well developed, an increasingly powerful incentive to permanent, well-planned highway construction was joined with an excellent opportunity; and the result was a road-building record which lately has really been wonderful. The past four years have seen more roads surfaced than all the preceding years of American history. To-day we have four cross-continental highways, passable most of the year, and about four hundred and fifty thousand miles of improved roads. At the present rate of construction, we shall double our improved-road mileage in ten years or less. This sounds very encouraging until we learn that we are doubling our automobile registration in only four years. Because the number of motor cars increases so much faster than our highway mileage, even our present excellent road-building record may have to be exceeded.

Of course, such elaborate improvements cost us a good deal of money. Last year new construction contracts totalling eight hundred million dollars were awarded; and if the cost of maintenance and improvements on existing roads is added to this sum, the total highway bill of the United States for last year becomes one and a quarter billion dollars. Was this expenditure justifiable?

We must look to the automobile for the answer, because however desirable hard-surfaced permanent roads may be, our diminishing numbers of horse-drawn vehicles certainly do not require highways of the type we have been constructing. Data from all over the country enable us to answer: "Yes; costly roads are justified if the motor traffic is heavy enough." Under these conditions, the investment is returned in the shape of increased safety, longer life of the road surface, greater speed and comfort, and very considerable savings in fuel and automobile materials and repairs.

The gasoline savings are especially interesting. Investigations show that in general gravel or macadam roads in good condition require from the automobile at least ten per cent. more fuel per mile than concrete or asphalt roads, and that such roads when in poor condition often require much more than thirty-five per cent. increase in gasoline consumption. The fuel-saving possibilities of good roads may be demonstrated in this manner: on a mile of gravel road over which the traffic was at the rate of one thousand automobiles a day, the gasoline consumption was figured as being sixty-eight hundred gallons a year more than if a smooth surface permanent road were used. If the price of gasoline had averaged twenty-two cents a gallon during this year, the saving on fuel alone would have been fifteen hundred dollars a year, or perhaps one-fifth of the first cost of the road required to effect this economy. Since the gasoline saving depends seriously on the number of automobiles using the road per day, only very popular roads could be paid for out of fuel savings alone; but, on the other hand, many costly accidents are due to unexpected tire failures or similar effects of poor roads. Although tire wear is hard to measure with accuracy, good roads are said to have added as much as forty-five hundred miles to the lives of casings; and no one can doubt that immense savings in wear of all sorts are possible.

On the whole, few people doubt that good automobile roads are paying investments—investments which help decrease the cost of living and increase both national security and our individual pleasures. We do not worry so much over the size and steady growth of our road-building appropriations as over the efficiency of their investment and the methods of distributing the cost of these highways between heavy trucks, light cars, and persons not owning motor vehicles. We see highways constructed which wear out before they are paid for, sometimes because of poor construction, sometimes because of poor finance. Landowners object to paying for roads destroyed by automobiles and call for maintenance by means of high registration fees or gasoline taxes. Operators of light cars claim that most of this taxation should fall on heavy vehicles, and owners of trucks allege that they are already taxed excessively. Through our need for automobile highways, the motor car has brought to the engineers and legislators enough new problems to keep them busy a long time.

In America, this road-building boom was caused by the general use of the automobile. Then why is it that in Europe, where roads were excellent at the time the motor car was developed, the automobile is less popular than in America? The answer is found in the relative cheapness of American cars. The system of quantity production common in our factories makes possible selling prices considerably below those of European makers. Deliberate attempts have been made by Mr. Ford and several other American manufacturers to produce a car suited to people of moderate incomes. These manufacturers base their plans on two well-known principles: first, that the lower the selling price the larger the number of people able to afford cars, and second, the larger the annual production of standardized cars the greater the economies possible in manufacturing. Their attempts have met with such enthusiastic approval from the public that prices have been reduced again and again, each reduction placing the cars within the reach of more and more people. Moreover, improvements in design, materials, and manufacturing processes have continued steadily throughout this period; so that to-day the automobile is one of the few things which costs us less than before the war. If the 1924 dollar is used in defraying living costs, it buys commodities which in 1913 cost only sixty-two cents; but if it is used to buy automobiles, it will purchase one hundred and twenty-three cents worth of 1913 value.

Many of the improvements which caused this decrease in cost were shared with other industries. Just as bicycle manufacturers developed processes useful to automobile manufacturers, so progress in automobile engine design gave the aeroplane engine a running start. The experiments of the automotive engineers contributed a great deal to our knowledge of the heat-treatment of metals, the possibilities of aluminum and alloy steels, better methods of forging and pressing metals, factory management, labor control, and so on. In a thousand different ways entirely unconnected with automobiles, these improvements have increased our comfort and our leisure.

But in Europe, the manufacturing situation is very different. Since very few automobile makers have attempted to find a market outside the wealthy classes, low priced cars are scarce. Many European automobiles, especially the French cars, are produced by factories specializing in other products than automobiles; and since their production is small, it is not strange that their manufacturing costs are high even when they have the advantage of low wages. The importation of American cars is made difficult by unfavorable exchange, duties, embargoes, and the absence of service facilities, and the American manufacturers have not made serious attempts to operate very large foreign plants. It is true that the largest automobile factory in the British Isles is the Ford Motor Company's plant at Manchester, but what is its output of thirty thousand cars a year compared to the two million cars produced annually in Mr. Ford's American plants?

Another condition which makes the automobile more easily secured by Americans than by Europeans is the relatively high wages paid here for a given class of work. During the past nine years, Americans have enjoyed considerable prosperity, and the difference between European and American wages has become greater and greater. Not only are cheap automobiles available here, but they are less of a luxury for a given class of men than in countries where a narrower margin exists between income and necessities.

But even if automobiles were much more expensive than at present, the advantages of speed and rapid starting justify the use of motor vehicles by others than the wealthy. The old steam fire-engine, with its plunging horses and its trailing plume of smoke and sparks, was both picturesque and useful in its day; but the speed and power of the modern automobile truck carrying rotary pumps driven by gasoline engines has caused every city in the country gradually to replace its horse-drawn fire-fighting equipment with motor units.

Such emergency devices as physicians' cars and ambulances are in the same class as fire-fighting equipment. How many doctors own a horse to-day? And the horse-drawn ambulance, like the horse-drawn pumper, has practically disappeared from our streets. To-day even Houston's dog and cat ambulance is propelled by gasoline.

Another emergency use of the automobile appears in time of war, when one truck hauls the load of half a dozen horses at four times their speed, on a much more concentrated type of fodder, and into gas, confusion, and restricted quarters where horses would be difficult to handle. If proofs of their military value were needed, any number might be cited from the World War. Probably those best known to Americans are the aid furnished by the Parisian taxicabs at the first battle of the Marne, the supply of Verdun by motor vehicles, and the rapid transfer by truck of the American First Army from the St. Mihiel sector to the Argonne. Our opponents, the Germans, were seriously handicapped in this field by their need for petroleum and rubber substitutes; but in spite of this weakness, the Allies thought best to demand five thousand trucks in the equipment surrendered under the Armistice terms.

Fortunately for us, life is not yet made up entirely of emergencies, in spite of its speed. Fires and ambulances and wars do not meet us every day, but commerce does; and in civilized countries wherever you have commerce, there you meet gasoline vehicles. In commerce, cost of operation is of first importance.

Twenty years ago, the high cost of motor vehicles almost prevented competition with horse-drawn business vehicles; but to-day, the only conditions favoring the horse are very frequent or prolonged stops, light loads, or extremely bad roads. The decreased cost of operating automobiles and the increased wages of men, acting together, are responsible for the great fleets of delivery trucks, automobile busses, and taxicabs in commercial service. Owners realize that if the automobile saves enough of the time of passenger or driver, it is an investment paying dividends in terms of wage-savings even when its first cost is considerable. The same argument justifies the use of trailers and detachable bodies. Of course, a certain part of these commercial savings are passed on to the ultimate consumer and affect the cost of living.

Even when a business man does not own private automotive vehicles, he can secure their economies through public truck or bus lines. Both classes of service appeared in thickly settled parts of this country about 1910; and in sections much frequented by tourists, such as California and Florida, the bus lines became very popular. To-day, we have about fifty-one thousand of these vehicles in service. For short-haul freight work, the motor truck offers many advantages. Since freight can be carried direct from shipper to consignee, there is less handling and consequently less breakage. There are fewer delays in transit or while waiting for empty cars, and there is less expensive equipment tied up in congested terminals. The truck operators also have no expenses for purchase of private right-of-way, and until a few years ago there were comparatively few legal restrictions on either bus or truck lines. These last two advantages seem likely to be diminished considerably, for both railroads and taxpayers object to them. The taxpayer admits the desirability of low transportation costs, but he thinks the damage done to highways by heavy vehicles is greater than the tax paid by their operators. The railroads claim that competition with transportation agencies partially subsidized by the public is unfair to them and that the responsibility for continuous service and for accidents is unequal. The private driver and the pedestrian also have their personal troubles with the chauffeurs of vehicles whose size and weight encourage independence.

These difficulties are very like those existing between the electric street-cars and the jitneys. In each case, where competition has been keen there has resulted a certain amount of depreciation in quality of railroad service and a very noticeable decrease in new railroad extension. We are certainly reluctant to give up the advantages of the motor vehicle for short hauls and special service; but on the other hand, we are unable to do without the railroads for long hauls. The ideal arrangement would be a combination of the two services according to their peculiar abilities, turning over to responsible well-regulated motor companies service in inaccessible territory not paralleling railroads, the work of branch-line feeders, freight hauls of less than twenty-five miles, and the transfer of less than carload shipments between terminals in the same city. Such coöperation seems to be growing in popularity, for at the beginning of this year two hundred and sixty-four steam and electric railroads were using motor trucks to some extent for freight or passenger service. The Pennsylvania Railroad is a prominent member of this group. The results, as far as they have been reported, seem in general to be a small increase in profit for the operating company and a considerable increase in convenience and service to the public.

But not all automobiles are used for emergency or for commercial use. In the United States, there are seven and a half pleasure cars for each automobile truck, and even in Europe the trucks are outnumbered two and a half to one. Why have men purchased so many machines not necessary to their business, even when used for business at all? It is true that automobiles are comparatively cheap in the United States, but even Americans would not spend so much money on motor vehicles without hope of a considerable return of some sort.

In the case of the strictly pleasure car, this gain is often a saving of time and energy for other pleasures; but the automobile also makes its own peculiar contributions to worth-while recreation. What other form of highway travel makes fewer demands on the driver? What other form of transportation of any sort yields more easily to the whims of the traveler? This freedom from limitations and worries seems to be the automobile's chief attraction to the tourist. In its enjoyment, millions of Americans of all classes find health, recreation, and education. The demand for tourist service and the tremendous numbers of motorists visiting our national parks is conclusive evidence of the popularity of automobile touring as an American vacation.

Independent control of cheap, speedy transportation is also of prime importance to persons living out of touch with rail facilities. Twenty years ago, farmers were forced to depend entirely on horse-drawn vehicles for transportation between the farm, the market, the church, and the school. To-day, twenty-eight per cent. of American automotive vehicles are used by farmers. Only those who have lived in the country before the advent of the automobile can appreciate the blessings brought to the farmer by the cheap motor vehicle. In point of time, it decreases distances to one-half—perhaps to one-fourth. In consequence, wholesome recreation—a rare thing in so many rural communities—is much more readily secured, and farm labor becomes more easily retained. In almost every rural community, the automobile prolongs the school days of farmers' children; and in 12,500 American districts it is possible to supply at a reasonable tax, free transportation to consolidated rural schools with superior facilities. Without doubt, the automobile gives the farmer business advantages of many sorts; but the social advantages it brings him are very considerable also. Since half our population still lives in rural districts, these social and educational advantages may well be more important to the nation as a whole than the improvements made by the automobile in the farmer's economic condition.

But not all of the automobile's effects are good ones. This is not surprising, for history tells us that most labor-saving devices exhibit this two-edged characteristic to some extent. They result in leisure; and like leisure, they are as readily turned to destruction as to construction. Many labor-saving devices have provoked labor riots and economic disturbances, and it sometimes appears as if the most innocent inventions cause the greatest disturbances. The invention of the cotton gin made slavery profitable and aggravated sectional differences into a long civil war—a war made more destructive than previous conflicts by those same improvements in transportation which opened the West to settlement, by new and abundant metals developed for peaceful applications but equally useful for ordnance and armor, and by the beginnings of the interchangeable system of manufacture. Two months ago, one of our best periodicals stated that the largest single factor leading to the World War is not traceable to Napoleon or Bismarck or the ex-Kaiser, but to the steam engineer, James Watt—a member of a profession notorious in the past for its lack of political activity.

The automobile can furnish many contrasts of this character. Although in rural education it certainly plays a useful part, in higher education its utility is at least doubtful. In discussing this subject, certain northern college executives have expressed opinions which a local newspaper printed under the expressive headline, "Gasoline and midnight oil do not mix." And in the field of public morals as well as in education, we find the automobile commended for some effects and severely condemned for others. The farmers of Fort Bend County accuse Houston automobilists of all sorts of wanton trespasses. Most of these offenses are minor, irritating ones, but the motor car makes so easy escape from the consequence of broken laws that criminals of all classes find it a useful tool. It is very properly charged with a large share of responsibility for the lawlessness of the present day. It is also charged with a reduction in the popularity of church-going and with the supposed loosening of family ties.

But there are certainly arguments on both sides of these questions. What if the bank robber and bootlegger do find the motor car a useful tool? Cannot the police use it also? It is true that stealing automobiles is a thriving new criminal business; but in the days before the automobile, was it not necessary to provide drastic punishment for horse-thieves? Now that out-of-town excursions are so easily arranged, persons yield to the temptations of the links, the fishing party, and the picnic who might otherwise have attended helpful religious exercises; but are there not still others who attend such meetings only when aided by the same mechanism? Besides, no one really knows whether the automobile actually decreases church attendance or not. A man's opinion on this subject seems to depend on whether he tries to park his car near a church or a country club.

Regarding the effect of the automobile on family life, it can be said that the motor car may not only carry the young people away from home, but may with equal facility carry their parents right along with them if the older people make themselves pleasant enough. Home life is not strictly house life; and it is always doubtful whether life in a household from which one cannot escape has any value as family life.

Another serious charge is that the automobile becomes in many ways a party to waste and extravagance. For example, pleasure cars, like clothing, go out of style and for that reason may be discarded long before they are worn out. Again, the ownership of a car carries with it a certain social prestige and may provoke a certain amount of envy—two things for which many people are willing to pay a high price. These attractions, plus the genuine advantages of motor cars, have sometimes induced the purchase of automobiles by persons whose income did not justify this expense. Burdensome mortgages and sacrifices of various sorts are the result.

Sometimes the sacrifice is large families. Doubtless there are many comforts or luxuries aside from the automobile which convince the upper and middle classes of America that children are expensive luxuries; but the motor car certainly plays a part in the voluntary limitation of many a family.

At least one popular household magazine holds that the annual cost of owning, maintaining, and replacing a medium-priced pleasure car would amply cover the expense of rearing a healthy child to a self-supporting age.

On the other hand, the automobile has helped the cash-and-carry store to bring back to many people the old economical habits of personal marketing and cash payments —two habits which the telephone, the credit account, and the delivery service seemed for a time to be seriously diminishing.

In many ways, the careless use of the automobile results in the destruction of valuable material resources. Even when a car is being used for serious purposes, it may easily be hurrying us unnecessarily toward the exhaustion of our petroleum resources and the complication of our international problems. Every car with a smoking exhaust is consuming irreplaceable resources in the shape of wasted gasoline or lubricating oil. The automotive engineers realize this danger and have done astonishingly well in designing automatic devices which minimize the waste due to ignorant or careless drivers. The general public, however, is still unimpressed with the danger, even though it grumbles at the cracked and blended fuels which necessarily have taken the place of the old volatile straight-run gasoline. Because of this waste, it is still an open question whether our cheap automobiles with simple carburetors are not furnishing us with transportation at too dear a price.

Even if our gasoline were all used efficiently, we should require immense quantities of it. Last year we used seven and a half billion gallons and exported eight million gallons also. Moreover, our consumption increases rapidly. The gasoline production in 1923 was twenty-six per cent. more than in 1922. Is it any wonder that we have already used up forty per cent. of the fifteen billion barrels of crude oil which once formed our national reserve? If this consumption continues at the 1923 rate, our visible supply of crude oil will be gone in twelve years. We produce two-thirds of the world's oil supply at the expense of a depletion in our own reserve of at least five per cent. annually.

Do these figures mean that American internal combustion engines are doomed to an early death from starvation? No, for perhaps we may still supply them by importing petroleum or by developing other kinds of fuel. Unfortunately, we do not have at present satisfactory substitutes either for gasoline, fuel oil, or worse still, for mineral lubricants; but on the other hand, the technical bureaus of the United States government and many scientific organizations clearly realize the danger of this situation and work diligently to improve it. Not only do they preach to the individual consumer economy of existing supplies, but they work constantly to eliminate loss during oil production, refining, and transportation, and to develop substitutes such as shale oil, benzol and alcohol, powdered coal, and so on.

If these substitutes are not forthcoming soon, we may still be able to buy oil from other countries—if they will sell to us. In 1922, the petroleum reserve of the world was estimated at seventy billion barrels, of which the United States possessed nine billions. In addition, we control most of the Mexican production; but even so we can rely on only eighteen per cent. of the world's supply. The remaining eighty-two per cent. is in the hands of other nations—seventy per cent. of it in the hands of Great Britain. When our supply is gone, will Great Britain sell to us?

The answer depends on both the political and the economic situations. There are many reasons why every civilized nation must have large supplies of petroleum; and in the scramble for existing fields, a good many serious political problems have already arisen. Automobiles, industrial furnaces, aeroplanes, power-plants, submarines, and ships of all sorts must be supplied with fuels and lubricants both in peace and war. Oil fields rank in importance to-day with coal, iron, and nitrate deposits; and since petroleum is such an important weapon in both economic and military struggles, it would not be surprising to see embargoes placed on its export or wars fought for its possession. Although the automobile could not be charged with the whole responsibility for such a situation, its needs would certainly be an important contributing factor.

Another material consumed chiefly by the automobile and looming as a possible cause of foreign disagreements is rubber. Here again the automobile is not the only consumer. Rubber is essential for gas masks and for surgical, electrical, and scientific equipment; but three-quarters of the world's production goes into automobile tires. Moreover, most of this rubber comes to America for fabrication, the American tire-makers alone consuming two-thirds of the world's production. Last year, our output was forty-five million tires —three for each automobile registered. Now rubber cannot be produced in this country in any quantity, and the existing plantations are almost entirely under the control of other nations, especially Great Britain. It has been suggested that we should retain control of the Philippines and Santo Domingo and grow rubber in them for our own protection. Without doubt, a shortage of rubber would be a serious blow to us. One of our larger industries would be destroyed completely, and pleasure cars would be almost a thing of the past; but worse still, our army would be seriously injured.

This condition actually existed in Germany during the

World War. Although in 1912 her chemists had been confident of their ability to produce a satisfactory supply of synthetic rubber, in 1918 her trucks were running on slippery steel tires backed with inadequate shock absorbers, and thousands of the soldiers fighting for the nation which initiated gas warfare were dying for lack of proper gas-mask material. Great Britain's control of the world's rubber and petroleum resources has certainly created a situation full of interesting possibilities to the nation which leads the world in automobile use and manufacture.

Still another count against the motor car is its high accident rate. The insurance recorders tell us that fifteen thousand lives were lost in automobile accidents in the United States in 1923; but this figure is certainly too low, as most of us understand automobile accidents. The statistical method of classifying collisions holds the heaviest vehicle responsible. Thus, if a careless driver and his family are killed on a railroad grade-crossing, the records show a fatal railroad accident. Since we kill thirteen hundred people and injure four thousand more at grade-crossings annually, fifteen thousand deaths is not too many to charge against the motor car; but even on this favorable basis, the automobile is responsible for two-thirds of all the deaths caused by vehicles. This figure is four times the number of deaths caused by steam railroads and seven times the number caused by street railways. The remainder of the deaths caused by vehicles are due chiefly to the motorcycle, for as an accident maker, the horse is thoroughly passé.

A newspaper paragrapher has said that humanity is divided to-day into two classes: the careless and the carless; but if the pedestrian were not a good deal at fault, we should not find so many cities passing jay-walking ordinances and similar protective legislation. On the other hand, statistics show clearly that most often the blame for automobile accidents should rest on the driver. A recent Massachusetts report showed that seventy per cent. of their automobile fatalities were caused by the motorist and only twenty-four per cent. were due to the pedestrian. Excessive speed caused thirty per cent. of these deaths. Wisconsin reports reckless driving as the cause of fifty-five per cent. of her 1923 motor accidents.

The only encouraging thing about the situation is that although automobile fatalities seem to increase at the rate of about one thousand deaths a year, the death-rate per ten thousand automobiles registered is decreasing. Our traffic regulations and our educational campaigns among school children, motorists, and pedestrians seem to be having an effect. One safety slogan reads, "The best safety device is a careful man"; and the best way to manufacture such a device is by persistent instruction—if necessary, by compulsory education in a severe court.

In 1924, about a million people will be driving their first cars over our streets and highways. How shall we know that they are fit to assume this responsibility? How many of them will be children? In twenty-six States, anyone is allowed to drive a car so long as the machine carries a registry number. The education, examination, and licensing of all drivers by some system uniform throughout the nation is a precaution very seriously needed in America.

But although ignorance and carelessness are to blame for most of our automobile accidents, the situation is certainly aggravated by the design of our cities. Fortunately, many of these are still young and changing; and the automobile may very possibly have sufficient influence to force improvements. It has already shown its power to cause city growth in both area and population, and now it enforces its demands for wider and smoother business streets by traffic jams and by a mounting accident rate. The remedies for traffic congestion seem to be: the widening of streets where possible, the use of one-way regulations where widening is impracticable, the dilution of traffic by the paving of streets parallel to main arteries, and the general speeding up of vehicles by control systems like the one now in use on Main Street in Houston. Elevated sidewalks for pedestrians and vehicular subways in business districts have also been suggested. Perhaps these second-story sidewalks will also carry the moving platforms recommended twenty-five years ago by Mr. H. G. Wells and now being actually tried out in England and Jersey City.

Parking difficulties are less easily remedied than traffic congestion. In business districts, no-parking zones are tolerable if ample parking facilities exist on waste land not too far away. One-hour parking zones are nuisances in many ways and are of limited application. Second-story and basement storage helps somewhat; but up to date, no really first-class or general remedy has been discovered. Parking difficulties and the accident rate together are strong allies of the street railroad and sources of much concern to the automobile manufacturer.

It is entirely impossible to discuss in one hour all the effects of the motor car on our daily lives. Many of them merit individually the use of all the time allotted to me. Some can only be mentioned. Examples of such minor effects are the introduction into our ordinary vocabulary of many new words, chiefly of French origin; a widespread interest in machinery and a better general knowledge of it; perhaps some adverse changes in our physique and perhaps a quickening of our thoughts and reactions; the transportation of sportsmen into the field much oftener than in past years, with a serious effect on our wild life; a certain amount of assistance to scientific discovery and exploration in China, the Sahara, and the Antarctic region; and so on. The list is almost endless; and throughout its whole length we find evil mixing with the good. Will these faults restrict the future popularity of the automobile? The answer depends to a considerable extent on the individual car-owner. He is the only man who can really prevent gasoline waste and personal extravagance, and he can do much individually to prevent crime and accidents. His personal efforts, if guided by imagination and foresight and aided by his motor clubs and legislature, may perhaps postpone for many years our arrival at the long-expected automobile saturation density.

JOSEPH H. POUND

V

CHEMISTRY AND THE PETROLEUM INDUSTRY

MANY of the earlier races of mankind had some knowledge of petroleum and its allied substances. For example, there is a tradition that petroleum was used in the making of mortar for the Tower of Babel, while Herodotus is authority for a similar use of bitumen in the building of the Walls of Babylon, and the Chinese record their own use of natural gas for fuel and light before the Christian era. But the petroleum industry, as we know it, is preëminently a modern industry made possible by developments begun in the nineteenth century, and in progress to this very moment of the twentieth century, in engineering, geology, physics and chemistry.

Chemically, petroleum or rock oil is a liquid consisting predominantly of a mixture of hydrocarbons of several different series. The composition varies greatly from region to region where the oils are found. Some petroleums contain compounds of the paraffin series only, while others may have members of the olefin, acetylene, benzene, naphthene and cyclo-paraffin groups. Four hundred and forty-five of these compounds have been tabulated, but of this number not more than two hundred have been isolated in a reasonably pure state. Some of these compounds have been shown by Mabery to have a molecular weight as high as 1700. It is of interest to note that compounds of the paraffin series are found in the lighter fractions of almost all petroleums. These with the exception of methane, ethane and propane are present in and constitute the major portion of commercial gasoline.

In addition to hydrocarbons, petroleum contains sulphur in the free state and combined either with hydrogen alone or with both carbon and hydrogen. Nitrogen is always present but in widely varying amounts from traces up to 1.5 per cent. The oil as it comes from the well may be accompanied by water containing salt. In some cases the water will separate and may be drawn out from under the oil; while in others, the water and oil are emulsified and can be separated only by a special treatment to which reference will be made in a later section of this lecture.

The question of the origin of petroleum and natural gas has received the attention of many distinguished chemists and geologists. The various theories which have been formulated from time to time may be divided into three groups: first, those which attribute to petroleum an inorganic origin; second, those which consider it as derived from the decomposition of land vegetation; third, those which regard it as a product of decay of marine vegetable or animal matter, or of both.

The first to advance a general inorganic theory was Berthelot, who, proceeding upon the hypothesis of Daubree that the interior of the earth contains free alkali metals, ascertained, by experiment, that when carbonic acid or an earthy carbonate comes in contact with the alkali metals at a high temperature, acetylides are formed which will yield hydrocarbons when acted on by water under suitable conditions. He therefore expressed the view, in 1866, that petroleum may have been produced by filtration of water containing carbonic acid gas into the interior of the earth, where it would come in contact with alkali metals at an elevated temperature, under great pressure, and produce both liquid and gaseous hydrocarbons. In 1879 Mendeleef published his notable paper on the inorganic origin of petroleum. He ascribes its formation to the action of carbide of iron at high temperatures in the interior of the earth upon water which has penetrated through fissures produced in the earth's crust by the elevation of mountain chains, or by other changes. Both of these theories are considered inadmissible by geologists.

The second school, noticing the relation between petroleum and the oils obtained by distillation from peat, lignite and coal, believed that petroleum originated in one or all of these materials, but this theory had soon to be abandoned by the majority of observers. The objections to the theory that petroleum has been produced from coal are strengthened by the fact that the largest deposits of the former are situated in strata of a period which was not coal-forming, and are usually far distant from coal deposits. It is possible, however, that the particular land plants which are rich in fats may have contributed in some small degree to the production of petroleum.

Finally, there is the more generally accepted theory of Engler which considers petroleum to have an organic origin from marine organisms, both animal and vegetable. The limestones, conglomerates and sandstones serve as porous containers for the oil that is formed. In view of the circumstance that there is an alternation of similarly porous beds free from, and saturated with, petroleum in the California, Tennessee and Texas fields, it is evident that this material cannot have been derived from overlying or underlying beds, but has been generated by the transformation of organic matter in the strata in which it is found. The forms in which petroleum now occurs depend in large measure upon the presence or absence of atmospheric oxygen, since, by oxidation and volatilization, the naphtha or petroleum is slowly changed into asphalt or mineral pitch. In these extensive layers of porous earths and shales, there is a vast repository of hydrocarbonaceous matter which may eventually be made to yield an enormous quantity of oil by artificial distillation. Like all other organic matter, this is constantly undergoing spontaneous distillation, except where hermetically sealed deep under rock and water. Such evaporation or distillation has converted the animal and plant remains into oils, the light oils into heavy oils, and these into asphalt and other solid bitumens, the process being accompanied by the evolution of gas. The animal remains in the shales, like those of Texas, the large amount of nitrogen in the oil, and the fact that the fresh oils when exposed soon become the home of the larvæ of insects, support the theory that these types of bitumen are of animal origin. On the other hand, the petroleums of New York, Pennsylvania, Ohio and West Virginia are supposed to be of vegetable origin.

Some experimental evidence has been obtained which lends support to the Engler theory. By fractionation of the distillate from a lime soap of menhaden fish oil, Warren and Sotrer, in 1865, obtained members of the methane, ethylene and benzene groups, such as are found in petroleum. In Japan, petroleum has been prepared experimentally by dry distillation of fish oil with acid clay. Since such clay is found in all the Japanese oil deposits, it is concluded that Japanese petroleum had its origin in marine animals. This is in accord with the Engler theory which presupposes several stages in the formation of petroleum: First, putrefaction takes place, by which albumen and cellulose are eliminated, leaving fatty matters and waxes. The fats are then saponified, probably through the action of water, forming free fatty acids; and the waxy esters are either wholly or partially hydrolyzed. Carbon dioxide is next eliminated from the acids and esters and water from the alcohols, leaving hydrocarbons of high molecular weight. Finally, there is a forming of liquid hydrocarbons; the accompanying violent reactions causing "cracking" into lighter and gaseous products.

If Engler's theory of the formation of petroleum is accepted, it follows that none of this product can be present in certain parts of the world. For instance, no petroleum will be found in the immense regions occupied at the surface by rocks of the Archean or Algonkian age, or in those of later periods that are entirely of an igneous or intensely metamorphosed character. Thus, perhaps half of the earth's surface is ruled out at the start. Oil has been removed by natural means from formations of even moderate metamorphism. For example, the strata of the greater part of the Appalachian Mountain system, and other mountain masses, formed previous to Mesozoic time, are folded, faulted and broken and to an oil geologist are obviously unfavorable for oil, the latter having been removed during the mountain-making process.

Conditions essential to the occurrence of petroleum may be stated in the order of their importance: The presence of rocks of sedimentary origin and an absence of intense metamorphism; sandstones, limestones, sands or other strata that are sufficiently porous to hold oil; some source from which the oil may have been formed; such water conditions as not to prohibit the accumulation of oil in pools; suitable cover to prevent the oil from seeping away or being pushed to the surface of the earth by underground waters; and finally, a suitable structure to cause oil to be collected locally into pools, with the assistance of such other factors as water, gravitation and rock pressure.

For the occurrence of petroleum, strata of suitable character are essential in order to assure a reservoir, except where there is some substitute for porosity, either in the cavernous nature of the stratum or in the presence of joint-cracks or cleavage planes. Ordinarily the productive stratum consists of sand or sandstone in which the interstices between individual grains furnish the pores. In the case of sandstone, the location of an accumulation is determined not only by structure but by the degree of continuity of the stratum, positions of old shore lines, etc. Not all sandstone throughout an oil region contains oil, even when other conditions are favorable, one essential requirement being that the individual grains shall be sufficiently rounded to make the bed porous and that they shall be comparatively uniform in size, rather than an indiscriminate mixture of grains of all sizes as in the case of many conglomerates. Experimental tests on oil sands and other rocks have been made which showed that productive sands seldom have a porosity of less than 10 per cent., while it may be as high as 30 per cent.

Until a few years ago, geologists and chemists were unable to explain the absence of oil from the regions adjacent to some of the principal mountain systems in the world; and no exact guide had been discovered by which they could delimit the regions where oil may be expected from those where it does not exist. In 1915, however, White published a paper showing that in regions where coal-beds exist, the percentage of fixed carbon decreases in a regular manner from the anthracite regions, or regions of highly bituminous coals, to the softer bituminous coal regions, and that in travelling from soft to harder coal regions this ratio passes a line beyond which no commercial oil fields may be expected. This branch of the science is still in its infancy, though it has already been used to considerable advantage. Where these ratios have been studied and used it has been found that oil fields of commercial importance seldom exist beyond the 65 per cent. line and that commercial gas fields seldom exist beyond the 70 per cent. line.

While the evidences of the occurrence of oil which are commonly noted by the geologist, chemist or petroleum engineer are not such as are ordinarily seen and comprehended by the layman, there are, however, in most oil fields, certain surface indications which may have a definite bearing on the existence of oil, either in that particular locality or at a distance. The principal surface evidences may be classified as follows: oil seepages or oil springs; natural gas springs; outcrops of sandstones or limestones impregnated with petroleum or bitumen; bituminous lakes or other bituminous seepages; bituminous dikes; mud volcanoes; burned clays; occurrence of salt; and occurrence of sulphur. Any one of these frequently has some association with oil, but oil may occur at a great distance from the point where the evidence appears on the surface. To illustrate, it is a fact that a formation which reaches the surface of the ground at a particular point, and from which seepages of oil, gas or asphalt are seen to emerge, may descend at such an angle that the locality structurally favorable for the accumulation of oil lies many miles from the exposed outcrop. For this reason, it is generally poor policy to drill on or near seepages unless evidence exists that the main deposit of oil occurs directly below.

As previously noted, salt is frequently associated with petroleum. Water which accompanies petroleum is generally more saline than that normally present in sedimentary rocks. On the other hand, extensive masses of salt often exist entirely unassociated with oil. Consequently, recent theories of the origin of oil have in the main ignored any relationship with salt as a factor in the process even though in many Ohio, Texas, Louisiana and Roumanian fields, oil is associated with salt in such a manner that there appears to be a direct relationship. The credit of having discovered the closed saline-dome type of geologic formation containing oil, is due largely to Captain Lucas who, in 1901, drilled at Spindle Top and opened that well-known well. While this structure is typical of most of the Gulf Coast fields, it must not be supposed, that the presence of the geologic structure known as a saline dome is always indicated on the surface by a topographic dome, as many saline-dome pools are situated where the surface is practically flat. Even in the case of the Spindle Top dome, the bulge on the surface is only a few feet in height. Whether or not there is any particular surface topography indicative of a dome in a locality of this class, there is a very marked upward bending of the strata as they approach the edge of the dome.

A marked increase in the value of Geology to oil development is due to the evolution of the "Structural Theory" of oil occurrence proposed in 1910 as an offshoot from the original "Anticline Theory" of Hunt, suggested in 1861. This theory may be stated briefly as follows. By some organic or inorganic agencies, the petroleum and gas have come into, or been generated in, the porous formations in which they are found. The oil, gas and water in the formations—assumed to have been approximately horizontal at the time these substances entered them—were at first widely diffused in the porous formations. In many parts of the world they have remained in their diffused condition up to the present time. Here only small quantities of oil and gas, too slight for profitable development, have been found, and the dip of the rocks is very slight. Where beds have been folded, however, as in most of the oil fields of the world, the oil, gas and water have been allowed to separate and arrange themselves according to their relative specific gravities. This separation and concentration may have been assisted by rock pressure, hydraulic pressure, seepage, capillarity, molecular attraction, internal heat or other causes.

The application of chemistry to the petroleum industry is confined for the most part to what is known as the refining process which begins with distillation. The art of distillation is an old one. It was practised by the ancient Egyptians, and the alchemists of the Middle Ages made use of it in their endeavors to find the elixir of life. It is not surprising, therefore, that distillation was employed at an early date in refining petroleum for medical purposes. It is certain that petroleum was distilled in Russia in the eighteenth century and probably earlier, for Johann Lerche, who visited the Caspian district in 1735, found that the crude Caucasian oil required distilling to make it satisfactorily combustible. What is said to be the first attempt to make kerosene from petroleum was carried out in 1823 in a refinery erected by the Dubinian brothers in the village of Mosdok. About the year 1850 Baron Thornau secured the services of the famous German chemist, Liebig, in designing a plant for refining Russian petroleum.

The beginning of the petroleum industry in the United States may be said to date from about 1826, when Dr. S. P. Hildreth visited the oil springs of Ohio and reported that petroleum had great possibilities as an illuminant. A little later Seneca oil and American medicinal oil were put on the market and widely advertised as sure panaceas for most human ills. As early as 1833 Professor Benjamin Silliman, of Yale College, had carried out a number of distillations of petroleum in glass retorts; but his most important investigations were made on a sample of oil submitted by the Pennsylvania Rock Oil Company, a corporation formed in 1854 for the purpose of procuring surface oil near Titusville by the method of digging and trenching. Silliman's report, published on April 16, 1855, is a classic document on the chemical technology of petroleum. It brought out not only the economic value of oil but furnished information on the chemistry of petroleum which is of fundamental importance in modern refinery practice. Among other things, Silliman showed that petroleum differs essentially from the fatty oils and can not be regarded as a drying oil. The variation in the boiling point of fractions upon distillation proved that the distillates were mixtures containing many different compounds. Temperature alone was found sufficient to change the constitution of a large number of the compounds and to produce new compounds that were not present in the original sample. After the first distillation, all fractions contained a very small quantity of free acid which could be removed with weak alkali and water. The distilled oil did not attack clean copper, which showed the absence of corrosive properties and therefore indicated that it could be used for lubrication. Distillation at higher temperatures in a copper retort led to the production of a thick mass of pearly crystals of paraffin which could be separated and made into candles.

Even with all the valuable information furnished by Silliman, the Pennsylvania Rock Oil Company was not successful because of the high cost of obtaining the crude oil. However, in 1857 the idea was conceived of drilling through the rock for oil in the same manner as that used in drilling for brine. The result was the drilling, in 1859, of the

Drake well, which yielded about twenty-five barrels of oil per day. The success of this venture spread like wildfire and in a relatively short time drilling operations became common and there was a large production of oil.

Since the days of Silliman, petroleum research has lagged behind the rapidly growing industry. This is due in large measure to the manner in which the industry has developed. For many years the manufacturing problem was comparatively simple. The principal products of the refinery were kerosene, lubricating oil and paraffin wax. Gasoline was then a by-product for which but little use could be found, and most of it had to be wasted. There was, therefore, no incentive, borne of necessity in the industry, for research of a fundamental nature.

The first serious chemical problem of the industry came, without warning, when the Lima oil of Ohio was discovered. On account of its high sulphur content and its accompanying sulphurous odor this oil could be used for fuel purposes only. Canadian oil was of the same type. The problem of refining these oils was finally solved by Herman Frasch, who found that the sulphur and odors could be removed by heating the oils with copper oxide during the process of distillation. The researches of Frasch increased the value of these oils about seven-fold.

The problem of the refiner is to fill the demands made upon him for the many different grades of petroleum products now required by the industrial and scientific world. Originally, the crude petroleum was broken up into its fractions by dry distillation—that is by heating the oil directly and then condensing the various fractions as they came over. Later, steam distillation was found to be more efficient. By blowing superheated steam into the oil the fractions come over at a lower boiling point, thereby preventing any overheating of the contents of the still and thus securing much better distillation.

The fractions obtained from distillation are separated empirically. Thus, by distilling and then redistilling the original fractions, such commercial products are obtained as petroleum ether, naphtha, gasoline, kerosene, gas-oil, stove distillate, fuel oil, lubricating oil, lubricating grease, paraffin, asphaltic residue, tar, etc. Before the time of the automobile, refineries used to attempt to pass off gasoline as kerosene and many disastrous explosions resulted. Now the conditions are reversed and much of the so-called kerosene of yesterday is being sold as the gasoline of to-day.

Each fraction, as it distills, contains impurities that may be detrimental to its use. Thus, gasoline is treated to remove sulphur and nitrogen compounds so as to improve its quality, odor and color; lubricants are treated to remove carbon and sulphur and to improve their appearance. Sulphuric acid is most frequently employed as the purifying agent. In the process, the distillate is agitated with a dilute solution of acid which gradually attacks the resinous and tarry bodies found in the distillate, partly decomposing them and partly absorbing them in a complex mixture which, on standing, separates as a dark brown layer below the unaffected hydrocarbons. Some of the sludge remains in the oil through adherence to the agitator or through incomplete separation. Many hydrocarbons form unstable compounds that are somewhat soluble in the oil. These conditions may result in the formation of stable emulsions during the process of washing. The addition of a small amount of water-soluble soap, and agitation with steam, will often break down such emulsions. Air may then be used to rid the oil of the haze that still persists. The acid treatment is followed by washings with dilute alkali for the purpose of neutralizing any acid that may remain.

Other chemicals, in addition to sulphuric acid, that are used in treating certain petroleum distillates to improve their color or odor are sodium plumbate, stannic chloride and calcium hypochlorite. In certain cases decolorization is accomplished by the use of absorbents such as Fuller's earth, Florida earth, bone and blood charcoal, etc.

Attention has been called to the fact that petroleum may contain large amounts of water emulsified in the oil. These emulsions must be broken down and the water removed before the oil is subjected to the distillation process. Various methods are employed to bring about a coalescence of the highly dispersed, colloidal droplets of water. Electrical methods are used with certain emulsions, while with others precipitation of the water is effected by the addition of electrolytes such as acids and iron salts or of water-soluble colloids such as sodium oleate. A commercial treating agent known as "Treatolite" consists of sodium oleate, sodium resinate, sodium silicate, phenol, paraffin and water. Heat alone causes some of the less stable emulsions to break down completely.

Probably the most important problem with which the petroleum technologist is confronted at the present time is the production and conservation of a maximum quantity of the highly volatile fractions that enter into commercial gasoline. The specifications for a satisfactory motor fuel require a certain ratio of light to heavier fractions and the supply of gasoline is determined by the supply of the lighter constituents. As far as the refiner is concerned the only direct means of increasing the more volatile fractions is the process of "cracking." By this is meant the breaking down of hydrocarbons of high molecular weight into lighter compounds, by the application of heat and pressure.

Although Silliman discovered, in 1855, that petroleum can be cracked, the first cracking process which was successful in producing gasoline on a large commercial scale was worked out many years later by Dr. W. M. Burton and his associates. This process consists essentially in heating gas or fuel oil under pressure. Beginning in 1906 processes were designed for heating the vaporized oil under pressure. One of the most recent developments is the use of catalytic agents such as anhydrous aluminum chloride and finely divided copper, which give a higher cracking efficiency.

In all cracking processes, both saturated and unsaturated hydrocarbons are produced. Since the unsaturated bodies react with sulphuric acid, the usual method of refining cannot be employed without entailing considerable loss of valuable gasoline constituents. To avoid this waste, cracked gasolines are desulphurized and decolorized by filtration through such media as silica gel, Fuller's earth or dehydrated bauxite containing one per cent. of finely divided copper or copper oxide.

There is considerable prejudice against cracked gasoline in the minds of many refiners and of the public in general; but this prejudice is not justified in view of the results obtained. The percentage of unsaturated hydrocarbons contained in cracked gasoline is usually higher than in gasoline derived from straight distillation; but the presence of such compounds is not objectionable providing the final product is suitably refined. Indeed, many writers consider cracked gasoline to be superior to the natural product as a motor fuel, since the former burns longer and delivers power during the entire stroke of the piston.

All the cracking processes now employed for making gasoline produce a considerable quantity of fixed gas which consists of saturated and unsaturated hydrocarbons. Working under assigned patents, the Standard Oil Company of New Jersey has developed and is operating a process for making higher alcohols from the olefines that are found in these fixed gases. This development has placed on the market a series of higher alcohols all of which have hitherto been exceedingly rare. It is now known that petroleum like coal tar affords a veritable mine of organic compounds—either furnishing the bases for making the compounds or the intermediates by which they can be prepared.

Unfortunately the domestic supply of petroleum is being cut down very rapidly by the enormous increase in the rate of production. In 1859 but two thousand barrels of crude oil were produced; in 1875 about nine million; in 1900 about 64 million; in 1910 about 210 million; in 1920 about 444 million; and in 1923 the enormous total of about 735 million barrels. In addition to this tremendous domestic output, 82 million barrels of crude were imported in 1923. It is of interest to note that the imports in 1923 were 45 million barrels less than in 1922. This marks the first large decrease since imports began in 1909, and emphasizes the changed conditions in Mexico and the falling off in the production of its Southern Field. In 1923 imports of light oil from Mexico constituted approximately 11 per cent. of the total as contrasted with 68 per cent. in 1922.

For the first few months of the year 1923, indicated deliveries were greater than production, but later they did not keep pace with the increasing output and between April and November were less than production. However, the sharp decrease in production during December reversed conditions and deliveries to consumers were almost equal to the production plus imports. Prices of crude oil in 1923, reflecting the conditions of oversupply, trended downward. On November 8th, the price declined to the low level reached during the deflation in 1921. However, in January, 1924, after the December decline in production and apparently, in anticipation of the decreasing supply, the market value had increased 25 per cent. of its low mark in November. The year 1924 opened with a distinct change in general conditions. Production, having been sharply checked, was soon less than consumption, so that it was necessary to draw on stocks. The peak of production may have been reached in 1923 and concern with regard to the condition of oversupply may soon give way to anxiety as to a source of petroleum adequate to meet the ever growing demands. But from virtually every producing field in the country and many prospective ones, come reports of preparations for greatly increased drilling activity. Many in the industry do not see any definite indication that a serious situation is imminent. It is pointed out that crude production, despite the falling off in the big fields in 1923, is now running approximately 200 thousand barrels daily above the output of this time last year, while at that time there was an additional 200 thousand barrels going into storage every day. All the large companies are expanding their plants and are building storage for vast amounts of crude. When there was a flood of crude and the price was low these companies bought crude and put it in storage. The fact that stocks are being drawn from storage at the present time, would seem to indicate good business judgment on the part of the refiners inasmuch as the cost of the stored oil was much less than the present market value of similar crude.

Whatever may be the condition, there certainly is need for conservation of this enormously valuable national resource. That gasoline constituents can be extracted from natural gas and casinghead gas has long been known, but their recovery has become of commercial importance only within the past few years. In 1904 there were only two small plants producing casinghead gasoline; in 1911 there were 176 plants; in 1920, 650 plants produced 483 million gallons. The Bureau of Mines found that at 13 refineries, from which data were collected, 129 thousand gallons of gasoline were in 1921 being recovered from uncondensed vapors. And yet the magnitude of losses resulting from non-condensation of still vapors has been realized by only a small proportion of the refiners. The Bureau of Mines states further that 141 billion cubic feet of casinghead gas were lost during 1921.

Probably the greatest loss of gasoline at the refineries occurs through evaporation from storage tanks. On finished products, this loss is especially serious since it is at the expense of the most volatile fractions. Tests carried out at various refineries have shown that the average gasoline in standard steel tankage will lose about 6 per cent. per year, equivalent to over $20,000 for each 55,000 barrel tank. The obvious remedy for this is to provide means for keeping the tanks cool, for preventing diffusion, and for collecting and recovering the vapors. The Standard Oil Company of New Jersey has perfected a mixture, "Sealite", which consists of glucose, starch, glycerine, glue and calcium chloride well beaten with air. This product floats on the oil and so diminishes evaporation; it is insoluble in the oil, is incombustible and non-drying. Floating roofs for oil tanks are also in use which keep the free volume above the oil at a minimum. The tanks should be painted white since the increase in temperature due to absorption of heat was found by experiment to be nearly twice as great if dark instead of light paints are used.

Efficient fire protection is also necessary. Texas, alone, lost nearly a half million barrels of oil by fire in 1923. Originally the refiner placed his chief reliance on steam as a means of extinguishing fires. Unconfined tank fires yield quite easily to a blanket of carbonic acid foam which is produced, on the spot, by the generation of carbon dioxide in an organic extract. The foam expands and spreads rapidly over the surface of the burning liquid—each bubble being a high non-conductor of heat.

Losses at the refinery and in transportation do not represent all the inefficiency and waste. Tests made by the Bureau of Mines on a large number of motor vehicles, to determine the amount and composition of the exhaust gases produced under various operating conditions, have shown that the average automobile and truck as used in service, waste from 20 to 30 per cent. of gasoline by incomplete combustion. At least 50 per cent. of this loss can be prevented by correct carburetor adjustment. The average Ford touring car, driven under normal conditions, gives not more than 17.5 miles per gallon of gasoline; and compared with other cars, it should give 24 miles per gallon. One cause for this inefficiency is the present carburetting system which can be improved so that 25 miles per gallon may be obtained. If this one improvement were applied to all Ford cars in this country it is estimated that 400 million gallons of gasoline would be saved annually.

According to thermo-dynamics, both the torque and fuel economy of an engine are increased as the compression is raised. Logically, then, the next step is to decrease the clearance volume above the piston, thus increasing the pressure at which the fuel mixture undergoes combustion. But such a procedure gives rise to a violent "knock" in the engine, the intensity of which increases with the pressure.

It has been found recently that this "knock" can be eliminated by the addition to gasoline of a small fraction of one per cent. of such compounds as tetra-ethyl lead and di-ethyl selenide. The effect of these compounds is probably due either to an increasing of the critical pressure at which detonation takes place or to a decreasing of the rate of combustion, so that no detonation occurs. So-called "anti-knock" or ethyl-gas gasolines are gradually being placed on the market by all the oil companies. This discovery gives an opportunity for revision in the design of gasoline-fired, internal-combustion engines so as to greatly increase their efficiency.

Although the supply of motor fuel that can be obtained by the present method of production is limited, there appears to be an almost inexhaustible amount locked up in crude oil in the strata, in shales and in the vegetable kingdom. About 75 per cent. of the oil in productive sand cannot be obtained by present methods of extraction. The Bureau of Mines, after a survey of the oil districts of California, estimates that over two million barrels of oil could be obtained from sand piles about the producing wells and from the outcroppings in the vicinity of the fields. The mining method seems to be especially applicable to the winning of oil in the numerous cases of upper oil sands not sufficiently productive to be of commercial importance by present drilling methods. Non-productivity of these upper oil sands may not be due to a scarcity of oil. It is possible that the oil is too viscous to flow or that there is insufficient gas pressure to force it out of the sand. In Alsace, there has been much success in the oil-mining venture.

Another depository of fuel oil is the oil-shale that occurs in enormous quantities in nearly all countries. Recently England has found in Northwest Somerset vast deposits that are located in a position particularly favorable for cheap mining. From each ton of shale 40 gallons of oil can be distilled. Practical mining engineers are of the opinion that there is a sufficient supply of oil in that area to meet the entire requirements of the United Kingdom for scores of years to come. Even now the shale deposits of Sweden are accessible enough at a cost of production that makes possible competition in the open market with crude oil from wells. The enormous deposits in South Africa yield as high as 100 gallons of oil per ton of shale. There are a number of rich deposits of oil shale in this country. Colorado shale gives a yield up to 65 gallons of oil per ton. Moreover, it may be remarked that oils obtained from shale have better lubricating values than those obtained from free petroleum.

Coal is another source of future oil supplies. If coal is carbonized by a low temperature process there is obtained: coke, gas, sulphate of ammonia for fertilizer, creosote, benzol, gasoline and kerosene, lubricating oils and greases, and a final residual oil which may be utilized as a fuel oil. The available benzol and motor fuel per ton of coal is about 12 gallons as compared with 4 gallons obtained by the usual high temperature process of carbonization. It is said that this material, from both a chemical and physical standpoint, is a true gasoline. If one-half of England's coal, as now consumed, were distilled, one-third of England's entire consumption of motor spirit could be obtained from the process. By this means, Germany derives the major part of her liquid fuel supply.

Vegetation offers a source of large quantities of liquid fuel, the utilization of which awaits only a proper cheapening and simplification of the process of converting cellulose to alcohol. Plants manufacturing alcohol from waste wood have been in successful operation in this country for some years. These plants obtain a yield of from 15 to 25 gallons of alcohol per ton of dry wood at a cost approaching the price of gasoline.

It should be pointed out, in conclusion, that the problem of increasing our motor fuel supply from sources other than petroleum is not sufficiently urgent at this time to demand the serious attention of technologists. However, with a gradual decrease in the output of petroleum the chemist and engineer will be forced to turn their attention to the efficient production of substitute fuels.

From this brief survey of the petroleum industry and the rôle that chemistry has played in its development, we must recognize that from the time of the first "commercial discovery" of oil in the United States, the resulting industry has been undergoing continuous development and expansion. The pioneers of this industry have been engaged in a contest of discovery, investigation and invention which has brought forth systematized methods in the production and utilization of petroleum. Looking backward, we may say of these pioneers that their spirit of adventure into the unknown recesses of the earth and their tireless efforts in laboratory and plant have been of immeasurable value to the people of the world. With their record behind us, we, in turn, face a future in which there will be universal demand for greater efficiency and economy in the production and utilization of a wasting asset. And we may look forward to a higher goal of scientific achievement in developing to fuller degree both the petroleum resources or those other natural resources which must be called upon eventually to contribute towards supplying the ever-increasing demand for motor fuels.

ARTHUR J. HARTSOOK

VI

SOME APPLICATIONS OF SOUND

ONE hundred and fifteen years ago, when Chladni, who has been called the "father of acoustics", published his treatise on sound, he made the following statement: "While important progress has been made in many branches of physics, the subject of sound has always remained behind." This statement expresses with more or less truth conditions which persisted up to the time of the Great War. In 1915 the relatively few physicists who were specializing in sound found their subject of research suddenly elevated to the top level of importance, and they were called upon to solve problems of the greatest practical significance. Every one has heard of the ingenious devices invented during the war for the detection and location of submarines in the water, of airplanes in the air, of big guns on the surface of the earth, and of miners or sappers under the surface of the earth.

In the field of these inventions it has been easy to beat the sword into the plowshare, for many of the war inventions have found ready application to peace-time pursuits; and while it is impossible to give a comprehensive discussion of these matters, there are a few which can be considered here. Then there are certain constantly recurring questions, questions some of which were answered long ago, but which are continually bobbing up in different forms in literature and conversation, such as, "Why do we hear distant sounds more clearly at night than in the daytime? Or do we hear them more clearly? Do sounds travel as well in a fog as in clear air? Why do telegraph wires hum on certain occasions and not on others? Why does the pleasurable effect of a musical performance depend so greatly upon the design of the auditorium in which the performance is given?"

These questions cannot be answered without a general knowledge of the nature of sound. The Greeks heard the humming of the wind through the trees of the forest and they explained the noise by saying that it was Æolus tuning up his harp. The Esquimos hear the wind howl about their huts and tell their children that it is Tornarsuk, the demon of the cold, who rides the north-wind and freezes men who venture out. These explanations of sounds are "human" explanations, and as such are probably more interesting to many people than the scientific explanations given in terms of pressures, velocities, and the laws of hydrodynamics; but we should not get very far if we relied upon Æolus or Tornarsuk to help us locate an airplane by sound, or to correct the acoustic deficiencies of an auditorium. We are obliged to invoke the aid of the much less romantic conceptions of pressure, velocity, frequency, and wave-length.

To begin with, then, let us consider the three different aspects of every sound. The source of any noise is always some vibrating object. This object may be a water particle in a thumping radiator, a set of wheels and levers in a ticking clock, or a mass of air in the poorly designed cornice of a building, which tortures the ears of its occupants with dismal moans whenever there is a high wind, but the vibrating object is there. It is the first essential in the production of sound.

Suppose I wave my hand back and forth. Here we have a vibrating object but you hear no noise. Suppose now I increase the frequency of vibration. If I could move my hand backwards and forwards at the rate of thirty times a second you would hear a very low pitched note. As I increase the frequency of vibration the note rises continuously in pitch. If my hand vibrates fifteen thousand times a second some of you would no longer hear a sound. At thirty thousand vibrations per second, or above, no one would be able to hear the tone produced. It appears, therefore, that a vibrating object must have a frequency somewhere between thirty and thirty thousand in order to produce an audible tone.

Now to analyze the matter a little further. Every time I move my hand forward I push forward the air layer which is in immediate contact with my hand. This air layer pushes neighboring air layers forward, and in time, if I have moved my hand vigorously enough, the air layer in contact with your eardrum is pushed forward. When these air puffs, or pushes, follow each other rapidly enough, the sensation on the ear is that of a musical tone. Here we have the second component in the mechanism of sound production, namely, a series of moving puffs, or pushes, in the air. We call them condensations, and speak of the rarefactions travelling through the air, or any medium, which we call sound. The sound is present, therefore, whether or not there is any ear to hear it. If an ear is present, however, we have a third feature to deal with. The air waves beating against the eardrum set it in motion and it is this motion which produces the sensation of sound.

One of the very remarkable things which the human machine is able to do is to sort out these extremely complex motions of the tympanum and bring them at will into the consciousness of the individual. The eardrum is always responding to numerous sounds—the rushing of the wind, the singing of birds and insects, the honking of automobile horns. Even if we tried to escape all this and went down to the bottom of a deep mine, say, we should still find our eardrums ceaselessly vibrating to the noises of our own bodily processes; for example, the rushing of blood through the blood vessels. The ear may be responding to thousands of different kinds of vibrations in the air, yet the brain is able to pick out one set of vibrations, possibly those corresponding to the voices of the people behind you, and you hear those voices to the almost complete exclusion, say, of a symphony by Beethoven. The ear can be trained to detect extremely minute differences in the character of sounds. Sir William Bragg tells of a blind naturalist, Mr. Wilkinson of Leeds, who, when taking walks in the country, is able to name different varieties of trees by the character of the sounds which they reflect or produce in the wind. He knows where the meadows are by the skylarks singing over them. Blackbirds mean hedges; a hush in another direction means that at some distance away there is a forest. Some blind men avoid collisions with large objects by listening to the sound of their own footsteps. The character of the sound changes when reflecting surfaces are near.

Let us now consider some of the characteristics of sound in the open air. A good many years ago the famous physicist and lecturer, John Tyndall, made a series of important experiments in connection with the question of fog-signalling. A sound battery consisting of trumpets, whistles, a steam siren, and three small cannon was mounted on a cliff of the South Foreland near Dover. Tyndall and his companions steamed about over the sea in an effort to determine the effectiveness of the signals. Very conflicting results were obtained, the greatest distance at which the sound was audible varying as follows:

May 19, 3 and 1-3 miles
May 20, 5 and 1-2 miles
July 1, 12 and 3-4 miles
July 2, 4 miles
July 3, 3 miles,

this being a calm, clear day with a smooth sea.

The explanation of these results given by Tyndall is based upon the fact that a sound wave is reflected when it strikes an unyielding medium, and also when it strikes a yielding medium. A sound wave striking a place where the air density is small encounters a yielding medium and there is partial reflection—also if it encounters a layer of denser air reflection occurs.

These facts are sufficient to explain Tyndall's erratic results. Speaking of his observations of July 3, he says: "As I stood upon the deck of the *Irene* pondering the question, I became conscious of the exceeding power of the sun beating against my back and heating the objects near me. Beams of equal power were falling on the sea, and must have produced copious evaporation. That the vapor generated should rise and mingle with the air so as to form an absolutely homogeneous medium was in the highest degree improbable. It would be sure, I thought, to rise in invisible streams, breaking through the superincumbent air now at one point, now at another, thus rendering the air flocculent with wreaths and striæ. At the limiting surfaces of these we would have the conditions necessary to the production of partial echoes and the consequent waste of sound. Air currents of different temperatures, as far as they existed, would also contribute to the effect."

The point is, that, if the sound is reflected by all these rising currents of hot air between the observer and the sound source, it cannot pass through. A non-homogeneous atmosphere is thus not good for conducting sound. It seems probable that at night the atmosphere, not being filled with rising currents of hot air, is often more homogeneous, and hence sound may be propagated better at night than during a hot, clear day. Tyndall found, in fact, that a cloud obscuring the sun for a short time materially increased the range of his sound signals.

If this explanation of the acoustic opacity of air is correct, we ought to be able to hear the reflected sound. Tyndall decided to test his theory by finding these echoes, so he landed and stood on the shore beneath his sound battery. He says: "From the perfectly transparent air the echoes came, at first with a strength apparently little less than that of the direct sound, and then dying away." The theory, therefore, appeared to be proved.

The observations which I have described are only a few of those which have been made. Rain, snow, or fog do not produce an appreciable effect on the propagation of sound; in fact, a fog is usually associated with a fairly homogeneous atmosphere, so that we frequently find the conditions of acoustic transparency associated with the optical opacity of the fog.

There is room for important application of the principles of sound transmission which I have been considering. Take the case of a locomotive whistle. In these days, when thousands of people are killed every year at railroad crossings, engineers and inventors are doing everything possible to stop this useless loss of life. The law places great emphasis on the locomotive whistle as a safety factor. However, a scientific efficiency expert turned loose on a locomotive whistle could probably save much money and many lives. The whistle is placed behind the smokestack so its sound must traverse columns of hot gases before reaching the crossing ahead. The sound is thereby diminished in intensity and is less likely to be heard. The disadvantageous position of the whistle, therefore, can result in the loss of life. On the other hand, if the same number of people are to be killed every year, that is, if the same sound intensity is to be used for the prospective victims, then much coal could be saved by placing the whistle in front of the smokestack and blowing it less vigorously. Professor A. L. Foley, to whom this idea is due, has figured, according to the daily press, that 2,434,026 tons of coal are consumed annually in generating steam to blow the nation's locomotive whistles. The cost of this coal is over seven million dollars. Instead of the low-pitched, or "chimes" whistle now in use, Professor Foley advocates a whistle with a single high-pitched note placed well forward on the locomotive. This change would result, he says, in a saving of many lives and of two-thirds of the coal now used—a money saving of over four million dollars.

Sounds produced by moving currents of air, or by high winds, are among the most common of our every-day experience. They are so common that we seldom stop to inquire closely into the nature of the mechanism producing the sounds. Many an old deserted house has owed its reputation for "haunts" to accidental peculiarities of structure which call forth uncanny moanings and groanings whenever a high wind is blowing. The Rice Institute Library at one time possessed one of these "haunts"; its supernatural character, however, was entirely eliminated by the presence of substantial brick walls, and also perhaps by stacks of books dealing with the theory of vortex motions in a turbulent medium. Forests have individual sounds depending upon the kind of trees which predominate. Pine woods produce a soft, high-pitched noise. Forests of oaks give off a dull roar. The causes of these differences of sound are not hard to find.

Consider a current of air flowing past an obstacle, say a stretched wire. We might expect that the air current which is divided by the wire would come together smoothly again after passing it, leaving perhaps a more or less turbulent region immediately behind the wire. Such, however, is not the case. The wind, passing by the wire, forms little eddies or whirlpools, first on one side of the wire, then on the other. It is easy to see that when these little whirls form they may give rise to lateral variations of pressure on the surrounding air. If these lateral pressure variations occur rapidly enough, a sound is produced. It is usually very feeble. Suppose, however, that the wire is not rigid. Then these little whirls forming alternately, first on one side of the wire, then on the other, may set it in motion, may make it vibrate. Of course the side pushes are very feeble, but if they come at just the right time they can produce quite a large motion of the wire. If I tap a suspended pendulum very gently I can still make it swing very vigorously, provided I time the impulses correctly. It appears, therefore, that if the side pushes on a telegraph wire come at just the right times to make it vibrate the way it naturally tends to vibrate, then a big motion can result. The wire in this case gives off a loud, humming noise, as if it were bowed by a violin bow. This hum is known as an Æolian tone. Now, it happens that the rate at which the little air whirls are formed depends on the velocity of the wind. Consequently it is only when the wind has one particular velocity that we hear the telephone or telegraph wires hum. For this wind velocity the frequency with which the little air whirls form is exactly the same as the frequency with which the wire tends naturally to vibrate.

When the wind blows past a broad flat surface, like the leaf on a tree, conditions are somewhat different, but there is still the same tendency for vibrations of the leaf to be set up. The nature of the sounds produced by such vibrations is of course affected by the form and size of the leaf. As I mentioned previously, the blind naturalist, Mr. Wilkinson, could name the variety of a tree by listening to the breezes blowing through its branches. He could distinguish between spring, summer, and fall by the changes in the character of these tree sounds as the season advanced and the leaves grew larger. The sound of the wind in a forest is a combination of Æolian tones from twigs and branches, with sounds made by vibrating and rustling leaves and branches. The net result may amount to a dull roar, the character of which changes with the velocity of the wind. It is said that in certain regions natives use forest sounds in forecasting the weather, a certain forest tone having been found to be the almost invariable precursor of a storm.

A question which was investigated a number of years ago by Lord Rayleigh is the following: how are we able to tell so accurately the direction from which a sound is coming? It appears that there are two factors to consider in this connection. If a sound comes towards me from the right it is a little bit weaker at my left ear than at my right. This factor is found to be not very important as far as locating the sound is concerned. The second factor is more important. If the sound comes towards me from the right it hits my right ear before it hits my left. The brain is able to detect this time factor and interpret it as a direction effect. The phase difference, as it is called, of the sound at the two ears is in most cases the decisive factor in locating sound sources. Since two ears are required, this ability, or this direction sense, is called the binaural sense.

If the sound strikes both ears simultaneously, it may appear to come from directly ahead, directly behind, or directly overhead, unless by turning the head one ear is moved farther from the source than the other. An intelligent dog, when listening to a faint sound, will cock his head first one way then the other. He has learned that in this way he can bring his binaural sense into play and locate the sound more accurately.

It is found that the binaural sense is considerably sharpened by the use of long listening horns attached to the ears. These horns have the effect of extending the ears, or of making the distance between the two ears much greater; the sound difference at the two ears is thus magnified. By using these horns it is possible to locate quite accurately the position of an airplane which may happen to be doing some night flying. We have to remember, however, in shooting at the airplane, that it may take several seconds for the sound to reach us from the distant machine, and during that time the plane will have moved on quite some distance. It will always be ahead of the place from which its sound appears to come.

The locating of big guns is a much simpler matter than the locating of airplanes, first, because a gun is confined to the surface of the earth and we only have to worry about two dimensions; second, because the noise of a gun consists of a single big sound wave, while that from an airplane is a series of waves. Also the gun is not apt to be a moving target. The method used by the British Army in locating big guns was simple and effective. At six different stations, well separated from each other, were placed microphones (very sensitive telephone transmitters). Wires from these microphones led to a central station where each microphone was connected with its own recorder. The sound wave from a big gun would strike the different stations at different times, since some would be nearer the source than others. These different times were all recorded on a moving strip of moving picture film. It was a matter of only a few minutes to develop the film, calculate the position of the enemy gun from its sound record, and telephone the proper range to the British batteries. The average error in calculating the position of a gun six miles away was only fifty yards. It is said that this method of locating big guns was responsible for putting more of them out of commission than any other method.

The locating of submarines by sound is a problem which was made familiar to many people. The exigencies of submarine warfare brought the methods in use to the front pages of the daily papers. There are different kinds of sound detectors for use in water. Here I will take time to mention only one—the simplest one. If we think of the water in the ocean as a medium which can transmit sound just as air transmits it, but four and a half times faster, we immediately think of locating sounds in water just as we locate them in air, by the use of the binaural sense. Obviously we cannot stick our heads under the water to hear these sounds, and since they do not come out into the air we must devise some way of getting at them. It is found that a stethoscope, very similar to the ones used by physicians, when immersed in water will pick up sounds. With a stethoscope connected with each ear the binaural sense comes into play and it is not very difficult to determine quite accurately the direction of the sound. It is largely due to the very extensive study, made during the war, of sound in water that we have two important practical developments. Instead of the old-time methods of sounding for depth with a line and sinker, the modern method uses a sound wave.

A ship sends out a sound into the water and listens for the echo from the ocean bottom. The time elapsing before the echo is heard gives the depth of the ocean, since the velocity of sound in salt water is known very accurately.

The second development is in connection with fog signalling. Recently the Submarine Signal Company has installed at the Fire Island Light near New York Harbor a signalling station which operates as follows. A series of sharp signals (dots) are automatically sent out both by radio and by submarine sound. They are sent out over both routes, the water route and the ether route, simultaneously. Now the radio signal travels about forty miles while the sound signal is travelling a distance of one foot. Hence when an observer on a ship receives the radio signal he knows the sound signal is just starting out. Suppose he gets the sound signal, say ten seconds later. Then he knows he is nine miles from the station, because sound will only travel nine miles in ten seconds through salt water. The radio receiver will give the direction of the station from the ship, so that its location is completely determined. This interesting method of safeguarding ships in fog or darkness will very probably be extended and developed, so that in the near future a sound receiver will be a regular equipment of all ships just as the radio now is.

There is one more phase of this subject, the locating of sound sources, about which not so much has been written. We have seen that the binaural sense is used for locating sounds in the air and in the water; it is also used for sounds in the solid earth. We have all read about the Indian scout who places his ear to the ground in order to hear the approach of his enemy. The modern warrior has improved on the ear. He uses a geophone, an instrument constructed as follows: A wooden box contains two partitions of thin mica, the space between being filled with mercury. Tubes lead from the air chambers on each side of the mercury. These tubes are connected with the ears. If this device is laid on the ground, the box picks up the sound vibrations, but the mercury, being very heavy, does not vibrate with the box. It is clear, then, that the air in the box will be compressed and rarefied as the box vibrates, so that the sound can be heard through the tubes.

In locating the source of a sound, one tube from the geophone is corked up, the other connected with one ear. A similarly arranged geophone is connected with the other ear. These two geophones are then laid on the ground at some distance from each other and shifted about till the sound appears to come from directly ahead. The source is then either directly ahead or directly behind the observer. Very little has been published about the use of geophones during the war. One account tells of a British mining party hearing sounds from a German countermine. These sounds steadily became louder till the voices and laughter of the Germans could be heard. However, repeated tests with the geophones indicated that the Germans would miss the British mine, so work was rapidly continued, the tunnel completed, and an enemy defense blown up. The geophone, you see, warned the party of danger; it also assured them of safety if they worked rapidly and quietly.

The war, as I have said before, brought to light new problems in the field of sound, and many of these problems were solved. There is one interesting phenomenon, however, which has as yet not been explained in a completely satisfactory way. It has been found that as one goes farther and farther away from a locality where heavy bombardment is going on, the sound grows fainter and fainter till it becomes inaudible. The surprising thing, however, is that by going still farther away one can hear the sound again. In other words, there appears to be around a source of loud explosive sounds, a zone of silence, perhaps fifty miles wide, and perhaps fifty miles distant from the source. Outside this zone the sound is heard. The following explanation has been suggested: When the sound travels outwards and upwards it enters upper regions of the atmosphere, where the percentage of lighter gases like hydrogen and helium is greater. A sort of reflection would result. (We have seen that sound is reflected when it encounters a change in the medium.) This reflection would cause the sound to return to earth again where it could be heard, at distances of one or two hundred miles from the source, outside the so-called silent zone. There are objections to this theory, but it is about the best explanation yet given.

Associated with these loud noises of guns or explosions are inaudible sound waves. Windows rattle sometimes before the sound is heard, sometimes afterwards. A lady thirteen and a half miles from an East London explosion was powdering her nose in a calm atmosphere. Suddenly a puff of powder rose from the open powder-box. Shortly after this she heard the sound of the explosion. A hundred and fifteen miles from the explosion windows rattled before the noise was heard. In the zone of silence there was no noise, of course, but windows rattled and pheasants were much disturbed, screeching in an extraordinary way at eight different localities where observations were reported.

It appears, therefore, that there are long sound waves, or air pulses, produced by explosions, which travel farther than the audible sounds, and it is these air pulses which break windows, affect barometers, and frighten pheasants. At the time of the Krakatoa eruption such a wave is believed to have gone completely around the earth three times.

It remains for future investigations to settle the exact nature of these waves, and also the exact cause of the silent zones, through which the long inaudible wave appears to travel while the audible is excluded.

Silent zones and long inaudible sound waves are not observed frequently enough for us to become thoroughly familiar with them. An element of mystery is therefore to be expected. There is, on the other hand, a whole group of very familiar phenomena which are more or less shrouded in mystery as far as general popular knowledge is concerned. Every one knows that in some halls or auditoriums it is very difficult to understand a lecturer. In others musical performances are not successful. The reason for these bad acoustic properties of certain buildings is not a matter of common knowledge. There are many well-known architects who appear to leave the acoustics of their buildings almost entirely in the hands of the god of chance, with the result that some strange anomalies have been produced. Cathedrals with interiors which delight the eye have been made the playground of little demon echoes which bound from vaulted roofs and fluted pillars to confound the ear of devout auditors. In the attempt to snare these demons miles of wire have been strung about the interiors of churches and auditoriums—all to no purpose whatever. They cannot be caught on wires. They are most successfully stopped by sheets of soft hair-felt, such as is used as a ceiling in our City Auditorium, but unfortunately hair-felt can sometimes look too much like a haven for rats to appeal to the interior decorator as a suitable medium for self-expression. The problem, of course, is one which should be settled before it arises. The architect of a building to be used for public speaking or for musical performances should be familiar with the principles of architectural acoustics, or he should secure the services of an expert in this line.

Each building usually presents its own problems, but there are certain general rules which have been worked out and which are easy to apply. Suppose I clap my hands in this auditorium. The sound can be heard for an appreciable time. With no audience in the room the sound lasts a little over three seconds. It is easy to see why the sound persists, why we have this reverberation, as it is called. The sound from my hands strikes the walls, is reflected, passes through the room, is reflected from the opposite walls, and so on, growing weaker at each reflection because some of the sound is absorbed by the walls at each reflection. In this room, when it is empty, the noise of a handclap travels well over half a mile before it becomes too weak to affect the ear.

Now consider the effect of this reverberation in the case of a rapid talker. While the sound of one syllable is still ringing in the ears of the audience he may utter four or five more. The result is a confusion. Sounds of different syllables or of different words are superposed upon each other. The louder the speaker talks the worse is the confusion of sounds. Yet he cannot talk too feebly or he will not be heard. His only recourse is to talk slowly and distinctly. In some halls the reverberation time is six or seven seconds. Obviously a lecturer who confined himself to even three syllables in six seconds would be intolerable. Hence some halls cannot be used for lecture purposes. Cathedrals usually have a long reverberation time. Recently an eminent English authority on sound warned newly-appointed rectors that their sermons must consist of just half the usual number of words; otherwise their sermons would not be understood.

As a result of the researches of W. C. Sabine we have a very simple way of cutting down the reverberation time. It is found that soft, porous materials, like cushions, draperies, etc., absorb sound. Sabine has shown that a certain area of sound-absorbing material is effective in cutting down reverberation no matter where it is placed in the room. This result is to be expected, for if a sound wave travels half a mile in this room, it is pretty sure to have been reflected at least once from every wall and pillar in the room. No matter where a curtain of absorbing material is placed, therefore, it will be hit by the wave and will absorb some of the sound.

The absorbing power of different materials has been investigated. For example, it is found that an oriental rug is about 0.3 as good as an open window of the same size in absorbing sound. Hair-felt is .78 as good. An isolated man is .48 as good as an open window; an isolated woman is .54 as good. With exact data such as this it is easy to see that the reverberation time of an auditorium can be calculated from a knowledge of its dimensions and the materials which it contains. Experience has shown that for speaking purposes the reverberation time for a hall of volume 216,000 cubic feet, when empty, should not be, in general, greater than three seconds. Consequently, since we know what the reverberation time should be, and since we know how to reduce this time at will, the problem can be solved quite easily. If a given hall is suffering from excess reverberation, the specialist should be able to diagnose the case without leaving his office, and should effect a cure by prescribing so many yards of chenille curtains, so many oil paintings, so many rugs or carpets, etc. He cannot prescribe a certain size of audience, so he does the next best thing—prescribes cushions for the seats. An unoccupied cushion is about half as good as a man at absorbing sound.

One reason why the best theatres have soft cushioned seats is that the acoustic properties of the theatre are then more nearly independent of the size of the audience.

The reverberation time depends to some extent on the pitch of the note. Two ministers were candidates for the pulpit of a certain Boston church. The first candidate, with a loud, low-pitched voice, failed to secure the appointment because the audience could not understand him. The successful candidate had a less powerful voice, but it was higher in pitch and was easily understood. Many of us have noticed this peculiar aptitude of certain rooms to respond, or resonate, to notes of certain pitch. It has been pointed out that the average man is most apt to burst into song while taking his morning bath. The probability is that the reverberation of the bathroom, which is freer from heavy draperies than any other room, seduces the singer into the belief that he possesses a peculiarly powerful and resonant voice—a belief which is often shattered by subsequent trials in a less favorable environment.

Reverberation is not the only source of trouble in the acoustics of auditoriums. There may be peculiar echoes. On one occasion the University of Illinois band was playing in their University auditorium. A xylophone solo with accompaniments by other instruments was featured. It so happened that the leader heard an echo more strongly than the direct sound of the xylophone, so he beat time with the echo. Players near the xylophone kept time with the direct sound. It is said that the confusion resulting was worse than is usual even in college bands.

The elimination of echoes such as this is secured by the elimination of large, flat surfaces which can reflect a great volume of sound in one direction. Practically all modern theatres have their walls and ceilings broken by recesses, coffering, and bas-relief. In addition to being decorative, these devices are often essential for the prevention of disturbing echoes.

In the history of architecture we find several instances where chance designs have resulted in extraordinary effects due to echoes. Faint sounds made in one part of a hall can sometimes be heard with startling distinctness at a far distant part of the room. A hall exhibiting this phenomenon is called a whispering gallery. Consider a room with a large smooth dome. A sound wave started at the centre strikes all parts of the dome simultaneously and is reflected back perpendicularly. The reflected wave converges to a point, in this case, the source, but it is easy to see that changes in the shape of the dome could cause the convergence point to be at some distance from the source. At this convergence point the original sound is very distinctly heard.

There are six whispering galleries in the world which have been made famous by some incident of place or association. They are the dome of St. Paul's Cathedral in London, Statuary Hall in the Capitol at Washington, the vases in the Salle des Cariatides in the Louvre in Paris, St. John Lateran in Rome, the Ear of Dionysius at Syracuse, and the Cathedral of Girgenti, Sicily.

The simplest of these and possibly the most perfect was the one at Washington. The guide would place tourists at symmetrical points beneath the large dome and they could carry on a whispered conversation across a very large distance. In the course of time deep hollows were worn in the marble tile where the observers stood. At present this unique property of the hall has largely disappeared because of repairs made on the dome. The smooth reflecting surface has been broken by coffering. Regarding the

Cathedral of Girgenti in Sicily, Sir John Herschel in the Encyclopedia Metropolitana says: "In this cathedral the slighest whisper is borne with perfect distinctness from the great western floor to the cornice behind the high altar, a distance of two hundred and fifty feet. By a most unlucky coincidence the precise focus of divergence at the former station was chosen for the place of the confessional. Secrets never intended for the public ear thus became known, to the dismay of the confessor and the scandal of the people, by the resort of the curious to the opposite point, which seems to have been discovered by accident." Sabine is inclined to doubt this story of Herschel about the eavesdroppers because of the very conspicuous position which they would be forced to occupy.

In the Salle des Cariatides in the Louvre are two shallow antique vases quite far apart. By a curious freak of construction a whisper uttered a little within the rim of one vase is partially focussed by it, still further focussed by the barrel-shaped ceiling, and is finally heard very distinctly just within the rim of the second vase. The Ear of Dionysius is the remains of an old quarry about a mile out from the present city of Syracuse. Tradition has it that Dionysius, the builder of Syracuse, once used this grotto as a prison. Being apparently a man of considerable ingenuity, he so designed his prisons that there was one point from which he could not only see everything going on in the prison, but could also hear everything that was said. The old quarry is supposed to have been one of these prisons. At present it possesses interesting acoustical properties, but the favored point from which one can see all and hear all is not as satisfactory as could be desired. True, it is on an upper level, fairly well sheltered, but reverberation renders difficult the understanding of words uttered on the main floor.

These examples which I have cited are all accidents—with the possible exception of the ear of Dionysius. It seems probable that with the knowledge we now have of sound and its behavior the functioning of most of these accidental whispering galleries could be improved by suitable changes of design. An architect or builder with the wealth and inclination of a Dionysius could easily surpass the works of the old tyrant of Syracuse. A business man, for example, who objected to the proximity of his stenographer could place her desk at a far corner of the room at a sound focus. By locating his own desk at the conjugate focus he could dictate to her, or carry on whispered conversations, no one else in the room being disturbed by the talk, or indeed, even being aware of it.

As far as I know, there is only one whispering gallery in the world which is not an accident—which was designed with the intention of being a whispering gallery. This is the dome of the State Capitol of Missouri. The completed structure is said to have fulfilled all expectations and is a source of great interest and astonishment to tourists.

In a discussion of sound and its applications very many people would rank as of fundamental importance a branch of the subject which I have not as yet even mentioned, namely, musical sounds. Any sound is said to be musical if the sound waves striking the ear are all similar and evenly spaced; hence musical sounds obey the same general laws as noises. There are also special laws governing the combination of different musical sounds to produce harmony or dissonance. Musical sounds are unique among other kinds of sound in that they possess the power of influencing and affecting thousands of people, perhaps more than any other kind of stimulus received through the sense organs. People can be influenced by music who are impervious to reason. To other people musical sounds mean no more than a succession of noises. In a physical sense these two classes of people are similar; they both have the same mechanism for hearing the sounds, the vibrating tympanum, the cochlea with its rods of Corti, etc., but there the resemblance ceases. The interpretative power, or value sense, is entirely different in the two groups of people.

It may be well, in a lecture which has emphasized so much the mechanism of sound, to mention, at least, the possibilities of enjoyment which may result from the development of this value sense for music. People who possess it certainly have open to them fields of pleasure which are closed to less favored mortals. It is possible to acquire a taste for music, though hardly through listening to a discussion of wave-lengths, frequencies, overtones, or Fourier's series. I have found a highly imaginative description of the sensations and pleasures which, possibly, many people experience when their ears are subjected to the ordered impacts of carefully chosen sound waves. This selection is from the letters of Sidney Lanier, the poet-musician. He says: " 'Twas opening night of Thomas' orchestra, and I could not resist the temptation to go and bathe in the sweet amber seas of this fine music, and so I went, and tugged me through a vast crowd, and after standing some while found a seat, and the baton tapped and waved, and I plunged into the sea, and lay and floated. Ah, the dear flutes and oboes and horns drifted me hither and thither, and the great violins and small violins swayed me upon waves, and overflowed me with strong lavations, and sprinkled glistening foam in my face, and in among the clarinetti, as among waving water lilies with flexible stems, I pushed my easy way, and so, even lying in the music waters, I floated and flowed, my soul utterly bent and prostrate." No one but a poet would dare express his feelings in this way in an ordinary letter. The quotation indicates, however, an ecstasy of pleasure such as nothing else can inspire. Could all of us possess even a small part of such enthusiasm as Sidney Lanier's, we should undoubtedly feel deeply grateful.

Having read a poet's description of musical sounds, I want to close this lecture with another quotation, which, it seems to me, might have been written by a music lover with a sense of the scientific. It is from "Peter Ibbetson" by Du Maurier. "The hardened soul melts at the tones of the singer, at the unspeakable pathos of the sounds which cannot lie; . . . One whose heart, so hopelessly impervious to the written word, so helplessly calloused to the spoken message, can be reached only by the organized vibrations of a trained larynx, a metal pipe, a reed, a fiddle string—by invisible, impalpable, incomprehensible little air-waves in mathematical combinations, that beat against a tiny drum at the back of one's ear. And these mathematical combinations and the laws that govern them have existed forever, before Moses, before Pan, long before either a larynx or a tympanum had been evolved. They are absolute!"

CLAUDE W. HEAPS

VII

PRIESTLEY AND THE DISCOVERY OF OXYGEN

FROM the earliest times until Joseph Priestley discovered oxygen in the latter part of the eighteenth century, fire was considered one of the great enigmas. Aristotle believed it to be one of the so-called elements, and that fire, together with earth, air and water, made up the entire universe. It was not held that these four elements were distinct kinds of matter which could be separated and identified; but rather that they were abstract qualities exhibited by one original, primordial substance. Each of the elements was characterized by the possession of two of the four qualities expressed by the adjectives: warm, cold, dry and moist. Thus, water was moist and cold; earth, cold and dry; and fire, dry and warm. Differences in the material world were therefore attributed to properties inherent in matter. Assuming that these properties can alter, it seemed to follow as a natural consequence that one form of matter could be transformed into another.

The immediate influence of the Aristotelian theory of the universe on the chemistry of the ancients was small; but it prepared the way for the reception of belief in the transmutation of the elements, an idea that dominated the minds of chemists or alchemists, as they were called, for many centuries. The labors of the alchemists were directed toward finding the mysterious philosopher's stone by the aid of which gold and silver could be obtained in abundance from the baser metals and the life of man prolonged.

While their search was in vain, the varied nature of their experiments had the effect of increasing, in no small degree, knowledge of chemical facts. But chemistry as a science can scarcely be said to have had its beginning until the latter part of the seventeenth century, when Robert Boyle taught that the real goal of experimentation was the acquisition of knowledge of the composition of bodies and the reasons underlying phenomena in nature, rather than the transmutation of iron or copper into gold. As soon as this lofty conception gained currency, chemists turned their attention once more to the baffling problem of the nature of fire and the phenomena associated with fire.

Conspicuous among the contemporaries of Boyle was the German chemist, George Ernst Stahl, who put forth the first comprehensive theory of combustion. According to Stahl's conception, all combustible substances such as carbon, sulphur, and metals capable of calcination contained a common volatile principle—phlogiston, or fire stuff—which escaped when they burned or were reduced to ashes. To illustrate, the burning of iron or coal may be represented as follows:

(Iron, phlogiston) — phlogiston = iron calx (ashes)
(Coal, phlogiston) — phlogiston = ashes;

the reduction of what we now know as iron oxide may be formulated thus:

Iron calx + (coal, phlogiston) = iron.

From this point of view a substance burned in air in proportion to its richness in phlogiston; thus, coal burned readily leaving but little ash because it was mostly phlogiston; iron burned less readily because it contained less phlogiston. The reverse process, the conversion of a calx (oxide) into a metal, was accomplished by heating the calx with a substance rich in phlogiston. The theory recognized dependence on the nature of the surrounding gas. When a substance burned or an animal breathed in air, it was supposed that the air gradually became saturated with phlogiston thus destroying its power to support life and combustion. The enclosed air in which a lighted candle had gone out or an animal had expired, was said to be full of phlogiston or completely phlogisticated.

The outstanding weakness of Stahl's naïve theory of combustion was phlogiston itself. Sometimes it was called a principle, at other times it was regarded as a substance; but the real nature of this so-called fire stuff was never clearly defined. On this account, the upholders of the theory were confronted with many difficulties in explaining the phenomena concerned with combustion. For example, it was found that when iron, say, lost phlogiston, that is, burned, the weight of the ashes was more than that of the element. A logical conclusion from this observation was that phlogiston weighed less than nothing. We may wonder how a conception that was so replete with errors and misconceptions could have taken such a hold on the minds of the scientists of the eighteenth century. But to appreciate their position we must remember that people still believed air, water and fire to be elemental bodies and that the modern view of combustion was possible only after the discovery of the element oxygen. It is to this epoch-making discovery and to the man who made it that attention is directed in the present lecture.

Joseph Priestley was born in Fieldhead, near Leeds, in 1733, only a few months before the passing of that other torch-bearer, Stahl. He was brought up among Calvinists of the strictest orthodoxy, and early in life became devoted to the profession of a minister of religion. Owing to ill health during his early years he was prevented from going to school and so was largely self-educated. At the age of twenty years, he was sent to the Dissenting Academy of Daventry where the outstanding policy was to encourage full discussion of every proposition with complete freedom. Priestley tells us in his autobiography that he usually found himself on the unorthodox side of a religious discussion. This native tendency increased with the years so that he passed from Calvinism to Arianism, and finally, in middle life, found for himself a credible and consistent theory of things in a broad form of Unitarianism. On leaving Daventry, Priestley became a minister, first at Needham and later at Nantwich. His early efforts were attended with little success either on account of his heterodox views or the difficulty he had in expressing them because of a tendency to stutter, a "thorn in the flesh" which troubled him more or less throughout his life. After this disappointing experience he decided to give up his ministerial work to become tutor in languages at the Dissenting Academy of Warrington. His versatility was evidenced by the fact that at different times during his ten years at Warrington he taught mathematics, natural philosophy, Latin, Greek, French, Italian, Hebrew, and anatomy, besides writing books and giving occasional lectures on logic, history and law. It is interesting to note that the book which superseded his on the "Laws and Constitution of England" was Blackstone's celebrated "Commentaries." In 1767 Priestley returned to his chosen profession, this time at Mill Hill Chapel in Leeds. It was here that he began his career as a theological controversialist and a defender of political freedom. While he carried out some scientific experiments during his six years at Leeds, his main efforts then and thereafter were devoted to theological work. He left Leeds to become librarian to Lord

Shelburne, who later as Prime Minister concluded peace with the United States. During this period he made his most important contribution to experimental science. After seven years with Lord Shelburne he once more accepted a call to become minister to a large congregation in Birmingham. This call was a particularly fortunate one, for he was well compensated and suitable arrangements were made so that it was possible for him to confine his ministerial duties to Sundays only, leaving the week days for work in science and for carrying on his numerous political and theological controversies.

By his forceful writings and his fearless public utterances through many years, Priestley came to be regarded as the protagonist of English Non-conformity as well as of political Liberalism. At one time or another he had had controversies with most of the leading divines of all schools of thought. And when the French Revolution broke out, he was one of its most ardent sympathizers, defending it with all the vigor characteristic of his nature. His invectives against Burke brought down the condemnation of Parliament, and the part he took in a local controversy in Birmingham roused public opinion against him to such an extent that a mob riot ensued on the evening of July 14, 1791, when a group of men had gathered together to celebrate the second anniversary of the taking of the Bastille. Priestley's church and home were sacked and burned and he was lucky to escape with his life. He fled to London where he hoped to be protected, but public opinion against him was so strong that he had great difficulty in finding a place to stay. George III expressed openly his personal satisfaction at the sufferings Priestley was compelled to endure. Finally he could stand it no longer and so emigrated to America in 1793, never to return to his native land.

From this brief survey of the activities of Priestley we see that he was first and foremost a theologian and a defender of political liberty. While he had a live interest in science throughout his life, he seldom allowed his scientific investigations to interfere with his life work. This should be kept in mind as we proceed to a consideration of the work which he put aside as of secondary importance but which gives him his chief title to distinction.

Priestley appears to have had a strong bent toward the study of nature from his earliest days. His brother Timothy tells us that as a boy he used to bottle up spiders to see how long they would live in the same atmosphere. As we shall see, this experiment anticipated in almost uncanny fashion the investigations which he undertook in later years. But he seems not to have devoted himself seriously to natural science until 1766 when he had the good fortune to meet the illustrious Benjamin Franklin, who was occupied, at the time, in defending the cause of the American colonists against the English Government. This acquaintanceship ripened into a warm friendship that had a far-reaching effect on Priestley's life. Encouraged by Franklin, he wrote a book on the "History and Present State of Electricity" that ran through five editions in the author's lifetime. In the preface to the first edition be manifested his scientific intuition in a striking fashion: "Electricity," he says, "together with chemistry and the doctrine of light and color, seem to be giving us an inlet into the internal structure on which their sensible properties depend." This prophecy has proved to be surprisingly true in the light of recent research on radioactivity and the electron theory. While preparing his book on electricity, Priestley discovered, among other things, the conducting power of charcoal and the phenomenon of the "alternative path," that is, the tendency of a high voltage discharge to take a short path of high resistance rather than a lengthy path of considerably lower resistance. His most important discovery in this connection was the law of force for electrostatic attraction, the generalization usually known as Coulomb's Law, although Coulomb's rediscovery was not made until eighteen years after Priestley gave the account of his work. The same year that these discoveries were made, Priestley received his call to Leeds and, fortunately for the science of chemistry, he happened to take up his abode in a house next door to a public brewery. Here he became very much interested in the carbon dioxide or fixed air, as he called it, which was evolved during the process of fermentation and contributed to the formation of the foam. Thus was started the long series of experiments on gases which gained for Priestley the title of "Father of Pneumatic Chemistry." When he removed from the immediate vicinity of the brewery, he was confronted with the necessity of making fixed air for himself. He heated powdered limestone in a gun-barrel and thus obtained fixed air, carbon dioxide, as well as inflammable air which was in reality carbon monoxide, a gas that he prepared on various occasions but which he never took the trouble to investigate until after he came to America. Numerous other methods were tried for making carbon dioxide and finally he hit upon the method of treating chalk with an acid, a stock experiment at the present day to which every student of chemistry is introduced early in his career. In this connection Priestley says: "When I began these experiments I knew very little of chemistry and had in a manner no idea on the subject before I attended a course of chemical lectures delivered in the academy at Warrington, by Dr. Turner of Liverpool. But I have often thought that, upon the whole, this circumstance was no disadvantage to me; as in this situation, I was led to devise an apparatus and processes of my own, adapted to my peculiar views; whereas if I had been previously accustomed to the usual chemical processes, I should not have so easily thought of any other, and without new modes of operation, I should hardly have discovered anything materially new." The apparatus to which he referred was the now well-known and well-nigh indispensable pneumatic trough. The first form used by Priestley was improvised from an earthenware tub used for washing linen. This contained water, below the surface of which was a shelf containing funnel-shaped openings. Over the openings were placed bottles filled with water. The delivery tube from the apparatus generating any particular gas was placed below one of these openings and the gas was collected by displacement of the water in the bottle.

The first paper on chemistry published by Priestley was in 1772 when he was thirty-nine years of age. This gave an account of his experiments on impregnating water with carbon dioxide by means of pressure. Even in Priestley's day this work had some importance besides mere novelty, for it was hoped that the solution now known as "soda water" might be of use in preventing scurvy. While such is not the case, there is no doubt that carbonated beverages have proven of real value in quenching natural thirst particularly in the depressing days of midsummer, and, by virtue of their sparkling evanescence, they are probably not without some psychic influence in allaying the artificial thirsts of these latter days. Priestley presented the results of his work on carbon dioxide to the Royal Society of London, which regarded it so highly that the Society at once conferred upon him its highest distinction namely, the Copley medal.

The same year that Priestley published his observations on carbon dioxide, he discovered hydrochloric acid gas, nitric oxide, and nitrous oxide. Hydrochloric acid gas being very soluble in water, its discovery was made possible by substituting mercury for water in his pneumatic trough. He first prepared the gas by heating hydrochloric acid with copper; but later found that the acid alone yielded the gas. He was then led to prepare it by the method that is most commonly employed to this day—the action of sulphuric acid on salt.

The preparation of nitric oxide or nitrous air, as Priestley called it, by the action of nitric acid on copper was a particularly important discovery, as it had a determining influence on his future work. As was his custom, he carried out numerous types of experiments with this new gas. To give you some idea of the diversity of these experiments, I will point out a few of them. He tested the antiseptic properties of the gas by preserving pigeons in it. He states that one preserved in the gas from the 28th of April till the 4th of June, had, on being cooked, a peculiar but not offensive taste. He heated the gas, nitric oxide, in the presence of iron and obtained the compound, nitrous oxide, familiarly known to most of us as the anæsthetic "laughing gas." He was made aware of his discovery by the fact that it supports combustion whereas nitric oxide does not. He therefore called his new preparation dephlogisticated nitrous air. Probably his most important experiment with nitric oxide was the use he made of it in the quantitative analysis of air. On account of the reactivity with oxygen, he was able to show that air was diminished by about one-fifth of its volume when mixed with nitrous air and exposed to the action of water. As we now know, this is due to the fact that the air is approximately one-fifth oxygen. But

Priestley's interpretation was that common air consists to the extent of about four-fifths of its volume of air which is already phlogisticated, while the other one-fifth is dephlogisticated and becomes phlogisticated by combustion, respiration, or by adding nitric oxide.

In this connection Priestley had observed, as early as 1771, that growing plants did not vitiate the surrounding air but that a candle would burn very well in air in which plants had grown for a long time. He conceived the idea that there was something attending vegetation that restored air injured by respiration or combustion. He demonstrated this conclusively by putting plants in air in which a candle had burned out and found after a time that the candle would burn in the restored air. He also showed that air which he had breathed himself until it would no longer support combustion, would do so after being exposed to the action of plants; and demonstrated that light was necessary for this effect as well as for the development of the green color in certain algæ. It was Priestley, therefore, who recognized for the first time that the action of plants and animals on air was not the same, but opposed, or, rather, complementary.

As a result of the observations on the comparative ease with which common air becomes phlogisticated by combustion, the natural question to arise was whether it is possible to get air that will support combustion better, or is less phlogisticated,—to use Priestley's terminology,—than common air. But Priestley apparently did not ask himself this question, and so regards his discovery of dephlogisticated air or oxygen as more or less accidental. In the initial paragraph of his classic paper[1] Priestley says: "The contents of this section will furnish a very striking illustration of the truth of a remark which I have more than once made in my philosophical investigations; viz. that more is owing to what we call chance, that is, philosophically speaking to the observation of events arising from unknown causes, than to any proper design or preconceived theory in this business. For my own part I will frankly acknowledge that at the commencement of the experiments recited in this section, I was so far from having formed any hypothesis that led to the discoveries I made in pursuing them, that they would have appeared very improbable to me had I been told of them." This introduction to one of the most momentous of papers in the history of chemistry is characteristic of the absolute honesty and sincerity of its author. Many a discovery has doubtless been made under circumstances no less accidental than the discovery of oxygen; but the discoverer is seldom so frank in admitting it.

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[1] Experiments and observations on Different Kinds of Air, Sec. III, p. 29 (1775).

Priestley employed a method of investigation, so persistently employed in recent years by Edison as to be called the Edisonian method, in contradistinction to the scientific or professional method; that is to say, he tried every kind of experiment he could think of on all kinds of substances. At the time he discovered oxygen, he was engaged in heating substances in a glass tube over mercury to find out what would happen, the heat being applied to the tube by a large burning-glass. The story of the discovery of oxygen is a brief one and I shall let Priestley tell it in his own words: "On the first of August, 1774, I endeavored to extract air from mercurous calcinatus, per se; and I presently found that by means of this lens, air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water to it and found that it was not imbibed by it. But what surprised me more than

I can well express, was, that a candle burned in this air with a remarkably vigorous flame, very much like that enlarged flame with which a candle burns in nitrous air, exposed to iron or liver of sulphur; but as I had gotten nothing like this remarkable appearance from any kind of air besides this particular modification of nitrous air, and I knew no nitrous acid was used in the preparation of mercurous calcinatus, I was utterly at a loss how to account for it.

"In this case also, though I did not give sufficient attention to the circumstance at that time, the flame of the candle besides being larger, burned with more splendor and heat than in that species of nitrous air; and a piece of red-hot wood sparkled in it, exactly like paper dipped in a solution of nitre, and it consumed very fast; an experiment which I had never thought of trying with nitrous air."

On the same day that he carried out the experiments with mercuric oxide, he heated red lead and obtained the same gas. Thinking there might be some impurity in the mercuric oxide originally employed, he repeated his experiments with a number of other samples with the same results. He had no idea at this time, so he tells us, of the real nature of the gas, but he could not get away from the notion that it must be nitrous oxide. And then, at the most important stage of the work for which he is famed, Priestley decided to take a continental trip. While in Paris he visited Lavoisier and performed the mercuric oxide experiment for him. Later Lavoisier claimed priority in the discovery of oxygen because Priestley did not know himself exactly what he had discovered; but the claim of the great French chemist was altogether unjust as well as unkind.

On returning to his laboratory after a two months' visit, Priestley convinced himself that the gas from mercuric oxide was not the same as nitrous oxide since the power of the latter to support combustion was appreciably diminished by shaking with water. As we now know, this is due to its rather high solubility in water as compared with oxygen. About this time Priestley tried heating sulphuric acid to prepare a gas in the same way as he had prepared hydrochloric acid gas. He had the good fortune to have some of the mercury he used in the pneumatic trough suck back into the hot acid where it reacted with explosive violence, producing clouds of a very pungent smelling gas. This led to the discovery of sulphur dioxide, a gas in which he became so interested that he forgot about his oxygen until March 1, 1775, when it occurred to him to add nitric oxide to it to see what would happen. To two measures of oxygen he added one measure of nitric oxide and found that it behaved like ordinary air. This merely led to the conclusion that it would support respiration. When he came into the laboratory the next day he tried the residual gas to see whether a candle would burn in it. Much to his surprise it still proved to be a better supporter of combustion than ordinary air. "I cannot at this distance of time," says Priestley, "recollect what it was that I had in view in making this experiment but I know I had no expectation of the real issue of it. Having acquired a considerable deal of readiness in making experiments of this kind, a very slight and evanescent motive would be sufficient to induce me to do it. If, however, I had not happened for some other purpose to have had a lighted candle before me, I should probably never have made the trial and the whole course of my future experiments relating to this kind of air would have been prevented." The succession of experiments that were tried are classics. He put mice in the gas and found that they lived considerably longer than in the same volume of common air. He then made a quantitative test of its goodness, so-called, by means of nitric oxide and found that it was five times as good as common air, an observation that accords very closely with the facts. The new product was named dephlogisticated air. He exploded hydrogen and oxygen and suggested that gunpowder be mixed with oxygen for making explosives. He anticipated the oxyhydrogen blowpipe by blowing oxygen into a flame and noting the extent to which the combustion was hastened. He suggested its possible use in medicine when common air was inadequate to support life. The final experiment which he records is particularly interesting: "My reader will not wonder, that, after having ascertained the superior goodness of dephlogisticated air by mice living in it, and the other tests above mentioned, I should have the curiosity to test it myself. I have gratified that curiosity by breathing it, drawing it through a glass syphon, and, by this means, I reduced a large jar full of it to the standard of common air; but I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that, in time, this pure air may become a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it."

Some historians mention Scheele in the same breath with Priestley as co-discoverer of oxygen, since the notes of the great Swede showed that he had prepared oxygen a few months before Priestley, although he never published his work. But this does not detract from the recognition due Priestley for his independent discovery. As a matter of fact, Eck de Sultzbach, in 1489, knew that red oxide of mercury gave off a "spirit" when heated. There are also indications that oxygen was known to the Greeks and that the Chinese were acquainted with the gas long before the time of Scheele and Priestley. For that matter Priestley himself had heated potassium nitrate in a gun-barrel as early as 1771, and obtained a gas with an enhanced power of supporting combustion.

The account of Priestley's discovery of oxygen as well as a number of other gases impresses one with his versatility in devising and carrying out experiments. But in spite of his unusual success in discovering new gases, he had little scientific imagination and his speculations regarding the composition of the substances he discovered were uniformly erroneous and unsound. He recognized clearly for the first time that the gaseous substances he prepared were chemical individuals and not mere modifications of one primordial air; yet he regarded water as the basis of all gases and considered it an element. This seems rather strange since he himself anticipated Cavendish in the synthesis of water by passing hydrogen over heated mercuric oxide; but he did not recognize the profound significance of his experiment. So deep-seated were his convictions that he was never convinced that his impressions were erroneous. With the discovery of oxygen by Priestley and the discovery of the composition of water by Cavendish, Lavoisier overthrew completely the phlogiston theory and established on a quantitative basis, the modern theory of combustion. But Priestley failed to keep pace with the developments and remained loyal to the phlogiston theory after every one else had given it up. Indeed, his last paper on chemistry written in America in 1800, four years before his death, was entitled, "The Doctrine of Phlogiston Established and that of the Composition of Water Refuted." This lack of scientific vision has caused some chemical historians to discredit Priestley's work as a chemist and to attribute his discoveries to accidental rather than rational causes. Indeed, Priestley himself is somewhat responsible for furthering this view as I have pointed out from time to time. But when we review his work as a whole, we are impressed with the brilliance of many of his investigations. It is true that the single apparatus, the pneumatic trough, was responsible for a great many of his observations; but Priestley invented the pneumatic trough. It is equally true that he would not have discovered hydrogen chloride, ammonia, silicon fluoride, and sulphur dioxide if he had used water instead of mercury in his pneumatic trough. But the fact remains that Priestley did not use water, but mercury, if the gas happened to dissolve in water. Although Priestley himself modestly attributes his discovery of the true nature of oxygen to the presence of a candle near at hand on March 2, 1775, there is no doubt but that he always had a candle near at hand; and I cannot help but feel that if he had not made the test on the day he did, he would have done so later on. While we recognize the random nature of his experiments, we must not forget that he had the ability to devise apparatus out of such articles as gun-barrels and washtubs and that he discovered more new gases than all his predecessors put together. Moreover, his work with nitric oxide laid the foundation of gas analysis and by a series of brilliant experiments he showed the complementary action of plants and animals on the atmosphere; and a hundred and fifty years ago he crowned his achievements with the discovery of oxygen. Thus, in spite of the apparent purposeless nature of many of his experiments and his shortcomings as a theorist, he holds a conspicuous place "among the swift runners who hand over the lamp of life."

Let us now give some attention to Priestley the philosopher, politician and theologian. In his own day Priestley's views found little favor with the masses, and, although he makes no particular pretensions to originality either as a philosopher or politician, his clear and unflinching expositions brought condemnation from a large body of his countrymen. As a philosopher he denied the freedom of the will in the sense of self-determination. He also denied the existence of a soul distinct from the body, and, as a logical consequence, he denied the natural immortality of man. According to the materialistic view which he advocated, the bodily and mental faculties—matter and spirit—are in the same substance and so they grow, ripen, die and decay together. He had a profound conviction, however, that man would be raised from the dead by the power of God and would thereafter be immortal. In his book on "Disquisitions Relating to Matter and Spirit" he states his position repeatedly. Thus, on page 247 he says: "The doctrine of the Scripture is, that God made man of the dust of the ground, and by simply animating this organized matter made man that living percipient and intelligent being that he is. According to revelation, death is a state of rest and insensibility, and our only though sure hope of a future life is founded on the doctrine of the resurrection of the whole man at some distant period; this assurance being sufficiently confirmed to us by the evident tokens of a Divine commission attending the persons who delivered the doctrine and especially by the actual resurrection of Jesus Christ, which is more authentically attested than any other fact in history."

Priestley's political conceptions were likewise not original but were based largely on those of Locke. But here again, his utterances were so outspoken that they commanded immediate attention. In his "Essay on the First Principles of Government" to which I have already referred, his thesis is that kings, senators, and nobles are the servants of the public and that government exists for the good of the governed. This leads him on page 13 to say: "But in the largest states, if the abuses of the government should at any time be great and manifest; if the servants of the people, forgetting their masters and their masters' interests, should pursue a separate one of their own; if, instead of considering that they are made for the people, they should consider the people as made for them; if the oppressions and violation of right should be great, flagrant and universally resented; if the tyrannical governors should have no friends but a few sycophants, who had long preyed upon the vitals of their fellow citizens, and who might be expected to desert a government whenever their interests should be detached from it; if in consequence of these circumstances, it should become manifest that the risk which would be run in attempting a revolution would be trifling and the evils which might be apprehended from it were far less than those which were actually suffered, and which were daily increasing; in the name of God, I ask, what principles are those which ought to restrain an injured and insulted people from asserting their natural rights, and from changing or even punishing their governors—that is—their servants—who had abused their trust or from altering the whole form of their government, if it appeared to be of a structure liable to abuse."

We can readily understand why George III was a party to the punishment inflicted on Priestley which ultimately drove him into exile and why the new American Government welcomed him with open arms.

As a Dissenter and a Unitarian, Priestley was deprived of many rights accorded to members of the state Church. He therefore had very definite opinions concerning Ecclesiastical Establishments which he did not hesitate to voice.

But as always, we find him reasonable in his demands, advocating the reformation rather than the immediate destruction of an established institution. In his "Essay on the First Principles of Government" he recommended four important reforms. First of all, he suggested that the Articles of Faith to be subscribed by candidates for the ministry should be reduced from 39 to 1. He considered it a reproach to any Christian establishment if every man could not claim the benefit of it who could say that he believes in the religion of Jesus Christ as it is set forth in the New Testament. A second reform suggested was to pay the clergyman in proportion to the work done; a third, to exclude Bishops from Parliament; and a fourth, complete toleration, so that every man might enjoy the rights of a citizen whether he belonged to the established church or not.

Thus in religion as in politics we find Priestley a staunch defender of rational freedom in thought and in action. While the religious and political freedom he advocated would be considered conservative in our day, yet he all but became a martyr to the cause he championed. Throughout the realm he was branded as an unbeliever in Revelation, a heretic no better than an atheist, a gloomy fanatic whom children were taught to insult as he passed along the street. And yet we are told that Priestley was anything but a gloomy fanatic. On the contrary he is pictured as being a cheerful and kindly soul, who was literally idolized by children and who never lost a friend. It has been said: "By some strange irony of fate this man who was by nature one of the most peaceable and peace-loving of men, singularly calm and dispassionate, not prone to disputation or given to wrangling, acquired the reputation of being perhaps the most cantankerous man of his time."

On the one hundredth anniversary of the discovery of oxygen a statue of Priestley was unveiled in the City of Birmingham. In a commemorative address delivered on that occasion Professor Thomas H. Huxley commended in particular the character of the man who was exiled for his honest opinions respecting church and state, nor if speaking to-day would Huxley alter one syllable of these two sentences[1]: "The unspotted purity of Priestley's life, the strictness of his performance of every duty, his transparent sincerity, the unostentatious and deep-seated piety which breathes through all his correspondence are in themselves a sufficient refutation of the hypothesis invented by bigots to cover uncharitableness, that such opinions as his must arise from moral defects. And his statue will do as good service as the brazen image that was set upon a pole before the Israelites if those who have been bitten by the fiery serpent of sectarian hatred which still haunts their wilderness of a world are made whole by looking upon the image of a heretic who was yet a saint."

On coming to America, Priestley went to Northumberland, Pennsylvania, where it was proposed to found a settlement composed mainly of Englishmen who had left their native land. This scheme was abandoned, but Priestley was so attracted by the beauty of the surrounding country that he decided to settle there and so built himself a house on a hillside overlooking the Susquehanna Valley. He was invited to accept the chair of chemistry at the University of Pennsylvania, but this invitation he modestly declined, declaring frankly that he was unprepared for such an appointment. "Though I have made discoveries in some branches of chemistry, I never gave much attention to the common routine of it and know but little of the common processes." However, he set up a laboratory at Northumberland and

[1] "Science and Education," p. 23 (1895).

here he fought until the end a losing fight to establish the phlogiston theory. He also built a little church in which he preached weekly until his strength gave out. He had hoped to found a college but this ambition was never realized.

In the "American Chemist" for 1874 appeared a communication calling on the chemists of America to celebrate the centennial of the discovery of oxygen and the birth of modern chemistry. This proposal met with so immediate and general response that, on the last day of July, 1874, there gathered together at Northumberland, Pennsylvania, the most notable assemblage of chemists that had ever convened on this continent, and in the course of this meeting at the grave of Joseph Priestley was organized the present American Chemical Society,—a perpetual monument to his memory.

During the simple ceremonies held in connection with the commencement exercises of last June for the breaking of ground for the new Rice Laboratory of Chemistry, Dr. Edgar F. Smith of the University of Pennsylvania generously presented to the Rice Institute from his personal collection the original of a letter written by Joseph Priestley. It would seem to be particularly appropriate that a copy of this old letter should find a place in the corner stone of this new edifice which is dedicated to chemistry, and is to be ready for teaching and research in the year that marks the one hundred and fiftieth anniversary of the discovery of oxygen.

HARRY B. WEISER

WITHERSPOON · & COMPANY · NEW · YORK ·

The Rice Institute Pamphlet is published at Houston, Texas, and is issued in January, April, July, and October. It was entered as second class matter, April 15, 1915, at the post-office at Houston, Texas, under the Act of August 24, 1912